VOL 1 NO 6 DECEMBER 1958

CONTROL

SYSTEMS · INSTRUMENTATION · DATA PROCESSING · ENGINEERING · APPLICATIONS

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CONTROLLING THE EXPLOSIVES

One hears so much about the power of the printed word, and indeed it is easy enough to find examples. It is, however, rare for a publication to make a permanent mark with its very first issue. Yet in fact this happened with CONTROL. In the July number this year—our first —we included a most comprehensive Buyer's Guide to control system elements and components and some 18,000 copies were printed. Many of these went to the Ministry of Supply, which has the responsibility for producing stores and equipment for the Armed Services.

Now as it happened officials of the Ministry had been concerned for some time with the problem of introducing a higher degree of automation in certain of its explosives factories, and the arrival of CONTROL gave them the lead they were seeking.

It seems that the Ministry's main problem was the organizing of a number of instrumentation and control system manufacturers and contractors into a fairly small group which could, between them, supply all the multitudinous items required for these very extensive and complex systems. With so many companies in the field this had proved very difficult, but the Buyer's Guide immediately suggested ways of doing this since all the items are conveniently classified into product categories.

As a result, this grouping has now been accomplished and work on bringing advanced systems to the factories has begun. CONTROL played no little part in bringing this about.

SIR! LETTERS TO CONTROL

The Editor welcomes correspondence for publication

Quicker construction

SIR: Here is an improved graphical construction for finding the time-constants of the system described by Dr Westcott in *Data Sheet 2* (August).

If k_1 and ω_1 are the measured values of the gain and frequency for continued oscillation in the system with the open-loop transfer function

$$\frac{C}{E} = \frac{k}{p(T_1p + 1)(T_2p + 1)}$$

the values of $1/T_1$ and $1/T_2$ can be obtained as follows. Draw a semicircle on a diameter AB equal to k_1 units, and draw a line parallel to AB at a perpendicular distance ω_1 units from it to cut the semicircle at C and D. Let P be the foot of the perpendicular drawn from C on to AB; then AP and BP are $1/T_1$ and $1/T_2$ units long. By using suitable graph paper, the construction can be reduced to a semicircle; the parallel and perpendicular lines are supplied by the rectangular grid.

Ferranti Ltd, Edinburgh R. S. J. GOOD

● *Thank you. We believe others will find this useful. Dr Westcott comments, 'Very good!'*—EDITOR

Begin at the bottom

SIR: CONTROL is superbly produced, but who is it aimed at?

The wealth of a nation—and its industries—can be represented by a triangle with the few rich at the top and the numerous poor at the base. Britain's national triangle today would have at its apex the most successful combines, few in number but vast in wealth. At the base would be the countless small businesses, with the remainder graduated in size and wealth between these two extremes.

Study of this triangle will show that greater national strength and prosperity demands greater production at the base. It is there one must start—leaving the few richer firms to their own devices.

But is not CONTROL doing the reverse? Your mathematics, your illustrations, your specialist articles are no doubt splendid. But, who is reading and looking at them? Where are the aids to the builder, the cobbler, the tradesman? What if all your effort ends in an oil refinery putting in a few more electronic devices? Will the refinery reduce staff and prices accordingly? And by what will Britain's economy have advanced?

Of course you may say your purpose is not to improve the output of the small and struggling. But I for one deeply trust you will not let so great a need slip by.

London, SW1 A. S. PLANE

● *We take your point about small firms. Indeed we have been alive to it since the early days of* CONTROL; *e.g. the Leader in the August issue discussed instrumentation in smaller works. We are now striving to find the best way of giving the plant engineer or production manager more to read each month in simple terms. But, Mr Plane, please remember control engineering, like all technologies, has its complications, and there are several thousand control and instrument engineers in this country who are not afraid to embark on a meaty article in* CONTROL *if it interests them and helps them in their work. Moreover the bright boys are not confined to the big combines; far from it*—EDITOR

Continued on page A45

SIR!

Continued from page A42

Numerical control of machine tools

SIR: I should like to reply to Mr Booth's points in his letter in the October issue.

If Mr Booth will read Section 2.2.1 of my article again, he will see that I clearly state the additional dimensioning time to produce change-point co-ordinates. These figures, of course, would be much higher where interpolation co-ordinates are required.

I was well aware that it was unnecessary to calculate the cutter centre path for the example shown in Fig. 3 on the basis of the data points for the work profile because of the simple nature of the outline, but Mr Booth is also well aware that, in the general case, these co-ordinates *have* to be calculated and that this represents most of the programming work.

In Section 2.2.2 I was not attempting to minimize the actual amount of Mr Booth's 'cutter-change compensation', as I prefer to call it, but to show that this should not be confused with automatic cutter-offset compensation.

The significance in his fourth paragraph is the statement that 'the dimension is limited only by the accuracy required'. This cutter-change compensation is an approximation, and it would be interesting to have Mr Booth's own figures for its accuracy. I think the appendix to my article (September) effectively answers his point about the need for such an adjustment.

Space will not allow me to quote figures to refute Mr Booth's contention that the same elements can be used satisfactorily for power transmission. But this idea ought to be an anathema to all control engineers.

I hope this has cleared up any misconception which may have arisen in your readers' minds after reading Mr Booth's letter!

Ferranti Ltd, Edinburgh D. T. N. WILLIAMSON

Need advertisements be 'waffle'?

SIR: I sympathize with Mr W. A. Cazeley, but, like you, I feel he has overstated his case in his own little piece of copywriting. What is wanted, surely, is not *mere* copywriters but *better* copywriters. Mr Cazeley's letter was obviously written at furious speed, but in my experience writing a technical article is a laborious task for most engineers. A good copywriter with engineering knowledge can, from a rough assembly of facts and figures, provide relatively quickly in concise and readable form the informative text described by Mr Cazeley.

Since I have chosen to defend copywriters, within limits, I feel I should also point out to Mr Cazeley that the end-products of even his superior labours have to be sold. It may be that in this respect he is at war with the system—but blame the system, not necessarily the copywriter.

Thomas Robinson & Son, Rochdale JOHN FINCH, *Publicity Manager*

Wrong number

SIR: The telephone number of Correx Communications Equipment (1948) is printed incorrectly in the firm's advertisement on p A34 of the November issue. The correct number is COLindale 7243.

Correx Communications Equipment (1948) Ltd. J. HARROWER, *Secretary*

CONTROL DECEMBER 1958 VOL 1 NO 6

Out of order

Far too many industrial instruments in this country are not working correctly. How often in visiting factories can one remark on a particular instrument and be told 'Oh! that's out of order: we don't use it'. Ask why it is not repaired, and the reply comes that 'it is more trouble than it's worth, but anyway the process operator doesn't need it and it's really not suitable for the job'. Here are three reasons for the instrument not being used: first let us look at the second.

Does the operator not need the instrument? That it was fitted at all shows that somebody felt the job could be done better by having its readings or records available. However good Jo Bloggs may be at measuring temperature with his thumb, colour with his eye, or humidity by the clamminess of his shirt, he does not work for ever. Nor can he be completely reliable. Today man can build more consistency into a device than he shows himself: when appropriate and economic such devices must be used. What if the instrument is really not suitable for the job? Modify it, replace it, or remove it, but do not leave it. No one keeps a sugar thermometer in his medicine cupboard.

But the heart of the matter is the first reason. Normally instruments that are not being used have broken down, and their owners find it hard or expensive to get them mended. Particularly is this so in smaller firms, who must usually depend on outside help. It would not be economic for them to employ a trained instrument mechanic, and the outlook and experience of the firm's engineering craftsmen may be quite unsuitable for handling delicate equipment, especially if it is electronic. This outside help normally comes from the instrument maker. One of the troubles here is geographical, for the bulk of the British instrument industry is in the South of England, and it is very expensive for a maker to send an expert several hundred miles to investigate a fault which may be due only to a dry joint or a worn bearing. Instrument firms that are large enough to maintain local maintenance depots are better placed, but of course they service only their own instruments.

Fear of servicing difficulty is indeed a stumbling-block in the path of greater instrumentation, and no doubt with this in mind SIMA devoted a quarter of the discussions at their Annual Convention last month to instrument maintenance and handbooks—with much helpful exchange of ideas between maker and user but without, we believe, any definite conclusions.

It is clear that large user firms cannot obtain sufficient numbers of trained instrument mechanics. Though they often send suitable electrical or mechanical craftsmen to instrument makers for specialized training, they need more men of the type who have taken the examinations in instrument maintenance of the City and Guilds Institute. Yet only eighteen students passed the final examination this year. Recent discussions with user industries are leading to a revision of the syllabus, and we urge firms to encourage suitable apprentices to enrol for relevant courses at technical colleges.

But the problem of instrument maintenance will remain with industry unless there is combined action. We suggest that central bodies such as BIMCAM, NIFE and SIMA should jointly tackle the problem. What is first needed is an investigation of instrument makers and user firms to establish the facts, and then recommendations to ameliorate them. In our view these recommendations might well embrace collective action by manufacturers—despite the obvious difficulties—to set up combined servicing units, perhaps assisted by the central bodies themselves.

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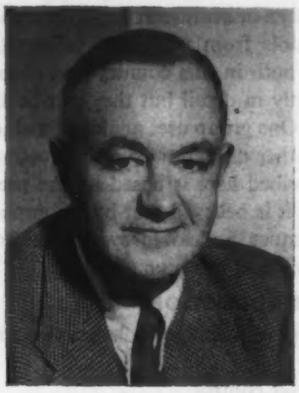


John Fielden, Founder and Chairman of Fielden Electronics, says

Why not British?

WE, AS A NATION, CAN CLAIM TO HAVE A LONGER industrial history than any other; in fact, our native ingenuity, enterprise and skill led the Industrial Revolution and has, over the years, kept us well in the forefront.

In the new industries such as aircraft, plastics and synthetic fibres, we can still hold up our heads with national pride, and our inventiveness in electronic equipment applied to radar techniques made a major contribution to Allied victory in the last war. However, when we in the British instrument industry consider our present position we must bow our heads in shame and admit that we have not made the progress we should have. Naturally there are notable exceptions, but by and large this is true. The plain fact is that much of British industry is equipped with instrumentation of American design. We cannot blame our customers, the users, for this, for they have bought the best equipment available, and I think it fair to state that most of them would much prefer to buy equipment of British design if it was available.

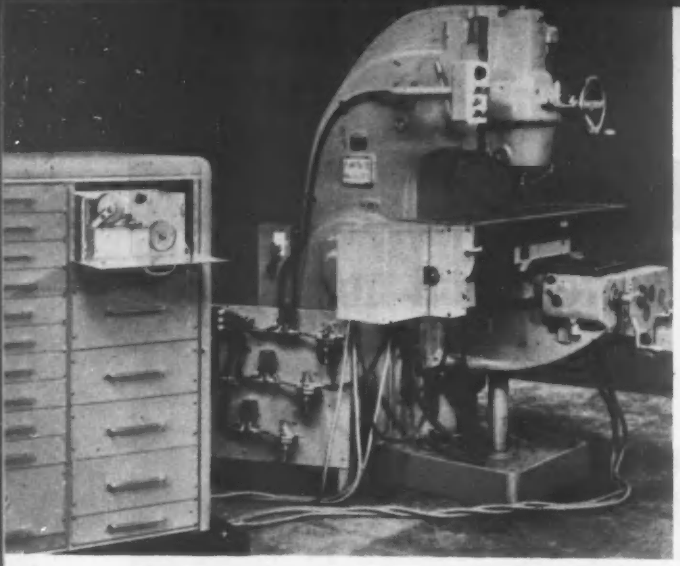
One large plant operator recently stated that he had to lag two or three years behind his American contemporaries in any new development depending upon advanced instrumentation, since new instruments were not produced in Britain until they had been fully evaluated in the American field.

On the success of the American sponsored industry in this country, we can have no comment other than 'The best man has won'. But I think we should have little pride in the fact that some of our larger British companies, with adequate resources and adequate capital, have taken the easy way out, and instead of developing British equipment for the British market have been ready to take licences from American sources, or to make copies of American ideas some ten years too late.

What is wrong with us? Are we to continue to accept this position of trailing behind the Americans? It is easy to find an excuse for the present position. Instrumentation during the last ten to fifteen years has gone through a complete revolution. We were well ahead in the days of pressure gauges and galvanometers, and, at that stage, we had no need to look around the world to import our ideas. The growth of the oil industry with its original natural source in America brought more complex forms of instrumentation needed to carry out the refining processes, and much money was available for this development. Naturally therefore this new complex instrumentation was produced for the first time on the other side of the Atlantic.

Surely we in the British industry are not going to let the position rest at that. The equipment developed for the oil industry by our American friends is largely pneumatic, with some electronic equipment which can now be regarded as belonging to the 'valve era'. Such equipment, in my opinion, has little place in the future; in fact, I see the beginning of a second revolution in which we use transistors throughout plant instrumentation, giving enormous advantages over all other systems. It is my ambition and, I hope, the ambition of British industry generally, to be in the van of this development. A careful study of this new technique brings into sharp focus the enormous advantages to be derived from its strategic use in instrument design, and the possibilities of producing instruments giving a higher performance at lower cost.

Stimulated by this desire to prove British enterprise, I earnestly hope that we will eventually demonstrate to the world that we are still capable of doing what we have done in the past, and that we can at least share on good terms the credit of instrument progress with our friends across the sea.



Programmed Machining

by **A. T. MACDONALD**, B.Sc.
Industrial Applications Division, EMI Electronics Ltd

In the controversy that rages over machine tool control systems the voice of Ferranti has already been heard in CONTROL (July). Here is a different and equally absorbing approach to the same problem

IN RECENT YEARS A NUMBER OF SYSTEMS FOR THE AUTOMATIC control of machine tools from numerical information have been introduced both in this country and abroad. The systems vary greatly in detail but they can be split into two main groups. One group uses analogue methods of measurement, the other digital or counting methods. The system to be described here is based on the use of analogue voltages, and it is believed that by the application of unique techniques a flexible system of good accuracy and reasonable cost has been evolved.

1. INTRODUCTION

The numerical control of machine tools has two main fields of application:

1. Continuous contour control
2. Discontinuous position control.

In the first the motions of the machine are continuously controlled to produce a profile. This is used in the production of two-dimensional or three-dimensional piece parts.

In the second the machine motions are controlled to move from one accurate position to another, the path taken between the desired positions being indeterminate. This is used for operations such as drilling and boring.

The present article will describe systems suitable for both these fields.

2. CONTINUOUS CONTOUR CONTROL

The continuous contour control system to be described uses five-hole paper tape as the input medium, with parabolic interpolation between defined data points. This interpolation is performed in the machine tool control cabinet, and thus the system is amenable to either hand programming using a desk calculator, or computer programming using a general-purpose digital computer. The quantity of paper tape used is small relative to the machining time, since on a two-dimensional system ten defined data points are encoded per foot of tape.

2.1 General description

A schematic diagram is shown in Fig. 1 for a two-dimensional system. The sequence of events leading to

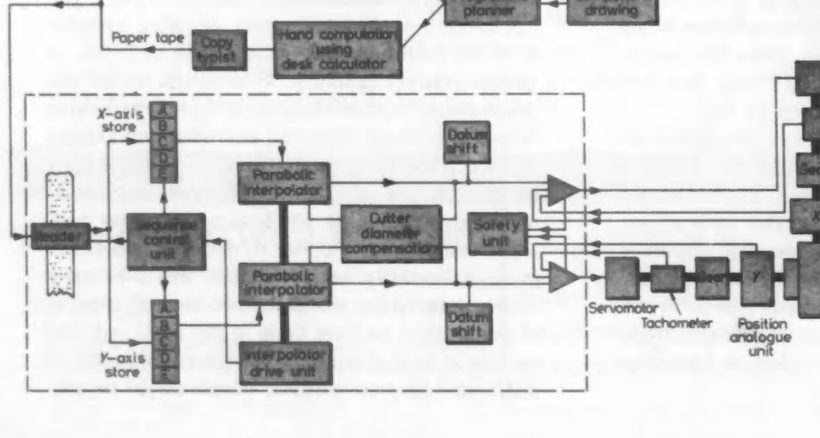


Fig. 1 A two-dimensional continuous control system. A programme produced from the drawing is punched onto tape. The tape on being passed through a reader is used to control the position of the machine tool

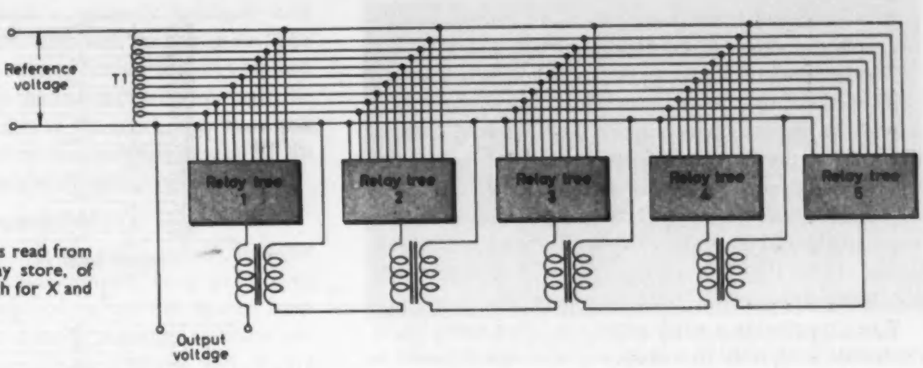


Fig. 2 The information that is read from the tape is passed to a relay store, of which there are two, one each for X and Y motions

production is as follows. From the engineering drawing, the programmer produces a table of co-ordinates of data points defining the desired contour. This can be done either by hand computation only, or partly by hand and partly by using a general-purpose digital computer. In either method the information is punched on to five-hole teleprinter paper tape.

The paper tape is passed to the operator, who loads it into the tape reader. The operator sets the work piece on the machine table, and adjusts the cutter diameter compensation and zero shift controls as required. During operation the information is read from the tape and passes to relay stores, one set for the X motion and one set for the Y motion. In these stores five data points are stored at a time. The parabolic interpolator receives three data points from the stores unit and produces an output for the X and Y motions, which is a smooth parabola passing through the data points.

The leadscrew for each motion drives a position analogue unit which produces a signal corresponding to the leadscrew position. This signal is compared with the demand signal from the interpolator and the resultant position error signal is used to control a servomotor. This motor drives the leadscrew to keep the error signal at a very low value. Since this is occurring simultaneously on the X and Y motions the tool describes the desired contour.

The measurement and computation are carried out using sine wave voltages at a frequency of 1000 c/s. The amplitudes of these voltages are an accurate analogue of the various co-ordinates.

2.2 The individual units

2.2.1 Stores unit

This comprises relays and toroidal transformers; its circuit diagram is shown in Fig. 2. The reference voltage is fed to a toroidal auto-transformer T1 which is tapped at ten equal intervals, these tappings being fed to five relay tree circuits. Each relay tree can switch any of the taps through to its output terminal as dictated by the information read from the tape. The relays have hold-on contacts so that the information is stored until the relays are cleared. The output of the relay trees are summed through transformers at progressively greater step-down ratios. Thus the first output is direct at 1:1; the second is stepped down 10:1; the third is stepped down 10:1 into the second output, and thus 100:1 at the final output. This is repeated for the fourth and fifth at ratios of 1000 and 10 000:1 respectively. Thus the output voltage is built up to correspond to a five-digit number. Five of these stores units are used for each interpolated axis, since five data points are stored at a time.

2.2.2 Interpolator unit

The parabolic interpolation between defined data points is carried out separately for the X and Y motions. It can be shown that if the X and Y co-ordinates separately follow a parabolic motion with respect to time, then the resulting path will be a parabola in the XY plane. The X and Y interpolators are mechanically coupled in the interpolator drive unit to ensure perfect synchronism. A circuit showing the principle of the interpolator unit is given in Fig. 3. The transformers T1 and T2 together produce the parabolic interpolation between points A, B and C. Should ABC be a straight line, the central tap of transformer T1 will be at the same potential as point 2 and no voltage will be induced in the primary of transformer T2. Therefore the outputs at the switch contacts will be a linear interpolation through A, B and C. Should the points A, B and C lie on a curved path—2′ will not be at the same level as 2 and a voltage will be induced in the primary of T2. The secondaries of this transformer are in series with the tapping points of T1 and the values of the turns are arranged in parabolic order. Thus the output at the switch contacts will be a parabolic interpolation through points A, B and C.

To ensure a smooth transition from one parabola to another this circuit is duplicated as shown, by transformers T3 and T4 and connected in the first instance to stores C, D and E. When the output is being taken from this circuit, the sequence control unit causes a switching action to occur which connects point 1 to store E, point 2 to store A, and point 3 to store B. Meanwhile stores A and B are cleared and set up for the next two data points. Thus a continual series of parabolas can be scanned with no switching transients. A further linear interpolation is carried out between the parabolic tappings by transformers T5 and T6. These transformers are connected to rotary stud switches in such a manner that a continual series of linear segments is produced, again

with no switching transients. If necessary the second sub-nterpolation can also be parabolic.

The interpolator input shaft is driven from a speed-controlled motor, the speed setting being governed from a knob on the machine control panel. The feed speed is governed by the distance between defined data points and the speed of the interpolator shaft. Since the point spacing is usually reduced when traversing small radii, the feed speed is also automatically reduced. A system is available which allows the feed speed to be kept approximately constant independent of the point spacing.

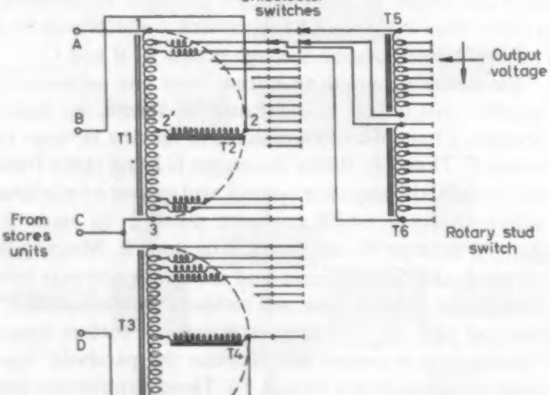
When machining a work piece it is often desirable to decelerate uniformly to a stop, e.g. if a sharp corner is being approached. With the parabolic interpolation it is possible to programme such a stop when machining a straight line. This is done by displacing the intermediate point of the final parabola from the mid-position.

2.2.3 Position analogue unit

This produces an output voltage whose amplitude is accurately proportional to the rotation of the input shaft. The unit is normally driven by the machine leadscrew, though it can be driven from a rack and pinion through a suitable gear ratio. The unit is made in three standard ranges, the full output voltage being obtained for an input shaft rotation equivalent to 100, 30 and 10 in. of table movement.

The principle of the unit is given in the circuit diagram of Fig. 4. The transformer T1 is an auto-transformer tapped uniformly throughout its length. It is fed with the reference voltage. The taps are connected to rotary stud switch S1 with make-before-break contacts. Each of the tap leads has connected in series a secondary of either the transformer T2 or T3. The transformers T2 and T3 obtain their voltage from the transformer T4 and associated circuits. This transformer is also tapped uniformly, the taps being connected to a rotary stud switch S2, again having make-before-break contacts.

Fig. 3 This unit interpolates between defined data points, and the operation is carried out separately for the X and Y motions



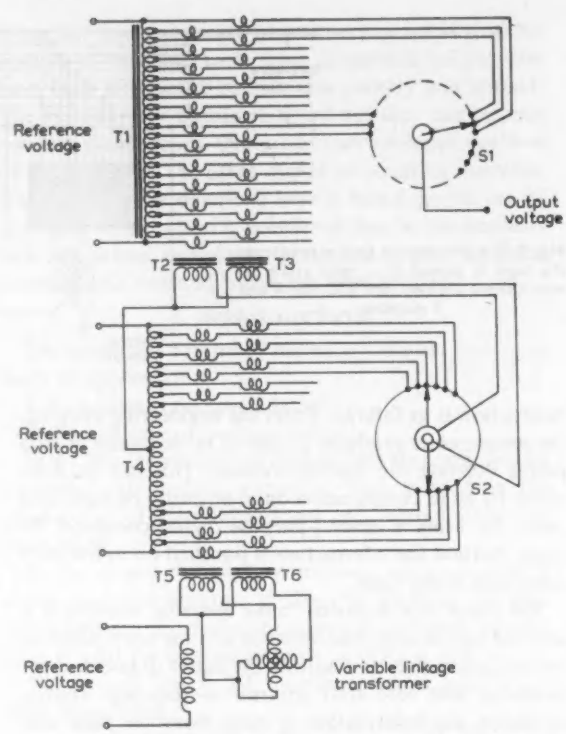


Fig. 4 The position analogue unit is normally driven by the machine leadscrew, and produces an output voltage whose amplitude is accurately proportional to the rotation of the input shaft

The switch S2 has two wipers 180° apart. The tapping leads connect to studs over an angle of about 225°. When the switch S2 is driven round, the output voltages from the wipers take the form shown in Fig. 5. These voltages are injected into transformers T2 and T3. The relationships of the voltages in the secondaries of T2 and T3 are such, that as one switch stud of S1 is midway above a tap point of T1, the next switch stud of S1 is midway below the next tap point of T1. The stud potentials are therefore equal, and the switches S1 and S2 are geared together in a manner such that the wiper of S1 bridges the stud contacts at this instant. An overlap region exists which ensures a smooth transition. By such means the output of S1 is a linear rising voltage over the full range of the reference volts. A similar circuit is used to inject voltages into the tapping leads between T4 and S2, these voltages being obtained from a variable-linkage rotary transformer. This ensures that the output from S1 is a smooth function of input shaft position.

Since the measurement is taken from the leadscrew, pitch errors and errors due to backlash will appear. Cumulative pitch errors can be eliminated by scaling the position analogue unit output voltage, leaving only the pitch to pitch variation. The backlash is minimized by split and spring-loaded nuts on the leadscrew. To reduce friction the leadscrews are of the recirculating ball nut type, and these are commercially available with an accuracy of 0·0005 in/ft length. The recirculating ball nut and screw is similar in operation to a normal ball

race bearing, so that with a properly hardened and ground screw and nut the wear will be negligible. The life of such leadscrews should be similar to that obtained from a ball race and as in the ball race will eventually be limited by ball failure. Later in the article a method will be described for correcting the residual errors by an auxiliary measurement taken directly from the table.

2.2.4 Cutter diameter compensation

The facility of being able to apply cutter diameter compensation at the machine console has proved to be of great value. The principle of the unit can be seen from Fig. 6. As the linear subinterpolating voltages are scanned in the interpolator unit voltages ΔV_x and ΔV_y are fed to a synchro resolver. The rotor of the synchro is servo driven to the null point of the resultant field, and thus the shaft is set to the local angle of the contour. Coupled to the shaft is a second resolver whose rotor is set at 90° to the first. The second rotor angle is therefore normal to the contour. The reference voltage is applied to the second rotor, and from the stator windings two voltages corresponding to the resolved components of the normal are taken. These voltages are passed through a scaling section which is set to the desired cutter radius. The outputs of the scaling section are injected in series with the X and Y demand voltages. The sense of correction is easily controlled by feeding the reference voltage to the second resolver through a reversing switch.

The present range of compensation is limited for reasons of accuracy to 0·3 in. on the diameter. The compensation amount is set on four dials graduated in 0·1, 0·01, 0·001 and 0·0001 in. Should the cutter diameter be less than 0·3 in., then the contour of the work piece is programmed and the full cutter diameter set on the dials. Should the cutter diameter be greater than 0·3 in. then any suitable nominal cutter diameter is assumed and the appropriate cutter path is programmed. Any difference between the actual cutter diameter and the assumed cutter diameter can be corrected with the compensation unit.

The unit can also be used to allow roughing and finishing cuts to be taken using the same tape. The first cut is taken with the compensation unit set to give an effectively smaller cutter diameter. The final cut is taken with the unit reset to its proper position. It has been found in practice that even if the tool edge follows the exact contour the work piece does not always come off exactly to size. This is probably due to reactions set up in the cutting process. The error can be minimized by setting the cutter diameter compensation unit accordingly either by trial cuts or from experience.

2.2.5 Datum shift unit

The desired contour is normally programmed relative to a datum point on the work table. The work piece has to be positioned on the table in the proper position with respect to the datum point. This can be a tedious task, especially if the work piece already has machined faces or holes, etc. The datum shift unit allows the work piece to be set in an approximate position only, the datum being shifted as required. This is accomplished by injecting voltages in series with the X and Y demand voltages. The datum shift unit can be used in two ways. In the first the actual position of the work piece relative to the datum is measured and any difference between this position and that assumed by the programmer is corrected on the datum shift unit. Alternatively, if the machine motions can be moved by hand the following method can be adopted.

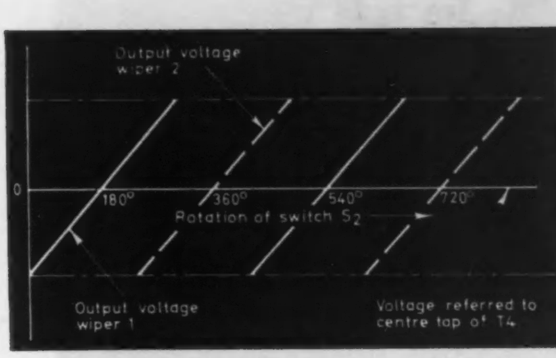


Fig. 5 The output voltages from the wipers of the intermediate switch S2 of the position analogue unit are of the form shown

The programmer encodes a setting point which will bring some datum point on the work piece, e.g. a reamed hole, under the machine spindle. If the work piece is incorrectly positioned the hand control is put into operation and the work piece positioned exactly under the machine spindle. This will introduce errors between the demand position from the cabinet and the feedback position. The datum shift unit dials are now adjusted until a null indicating meter is at zero. The programme will now be set up to the new datum. It will be noted that if a number of parts are being machined and a fixture is used the datum setting is carried out for the first part only. Owing to the analogue nature of the system, no further adjustment will be necessary for the rest of the parts.

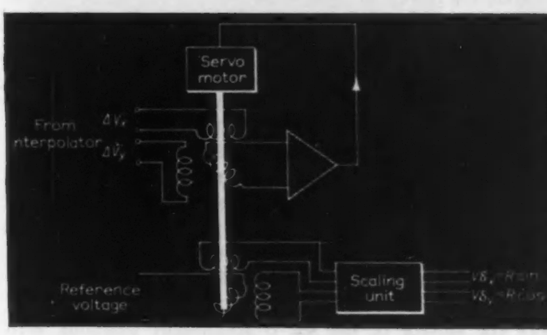


Fig. 6 Cutter diameter compensation unit

The datum shift unit is $\pm$ 10 in. for the 100 in. analogue range. The shift is set on dials giving 1, 0·1, 0·01 and 0·001 in. steps. If a number of small parts are being machined, more than one can be set on the machine at a time. Using the datum shift facility, these parts can be machined one after another from a tape corresponding to one piece part only.

To be continued

For new passenger ships the stabilizer is regarded as almost an essential requirement, and in many cases is worth while installing in older vessels says—

JOHN BELL, M.Sc., M.I.E.E.
Chief Research Engineer
Muirhead & Co Ltd

Servos bring stability at sea

WHY DOES A SHIP ROLL? AN ELEMENTARY QUESTION, BUT PERHAPS not so well understood as taken for granted. The first requirement of a ship is that it must float on the water, and the second, that it must remain upright as nearly as possible. A vessel is therefore designed to have its centre of gravity below what is called the metacentre (Fig. 1) and this involves so shaping the hull that the centre of buoyancy *B* moves to that side of the vessel to which it may be tilted, i.e. to B′, establishing thereby a righting moment. If the vessel were not so shaped, for example if it was cylindrical and the centre of gravity corresponded with the centre line of the cylinder, it would have no righting moment.

A ship may be regarded as a pendulum, supported by the buoyancy of the sea rather than from a fixed pivot. In Fig. 1 GM is the metacentric height, and is equivalent to the length of the pendulum, the suspension or pivot point being M, while G is equivalent to the centre of the pendulum bob (in the figure it is the centre of gravity of the ship). If the pivoting point is moved a pendulum will swing and with continuous and irregular motions of the point the pendulum will never come to rest. This is the equivalent to a ship in a rough sea since the surface of the sea is continually changing with constant changes in the position of the centre of bouyancy, such changes causing sea forces or moments which disturb the vessel from its otherwise vertical resting position.

The two characteristics of a pendulum are its periodic time, which depends on the length of the support and is the time taken for one complete swing; and the amount by which the amplitude of swing of the pendulum is decreased by each swing—this may be called the damping characteristic and is due to the friction of the air and pivot. Similarly, a ship has its periodic time of roll (swing) determined by the friction of the water on the hull and projections from the hull. In the days of sailing ships additional damping was provided in the sails and rigging and this was sufficient to have a marked effect on the amount of rolling experienced. The advent of mechanically propelled vessels, with clean shaped hulls for less resistance to the forward motion, led to increased rolling and many attempts have been made to reduce it.

It is well known that a small impulse if applied at the right time will cause a pendulum to keep swinging over a large amplitude and such is the case also with a ship—this is called resonant or synchronous rolling. Measurement, experience and calculation show that if the disturbing or sea force represents a wave with 3° slope and this is applied continuously at the resonant frequency, a ship with the normal amount of damping will roll 18° each side of the vertical. This amplification of 6:1 in the synchronous condition indicates how important it is to avoid synchronous rolling and also shows the desirability for a stabilizer either to oppose the sea disturbing forces or to increase the damping and so reduce the 6:1 multiplying factor.

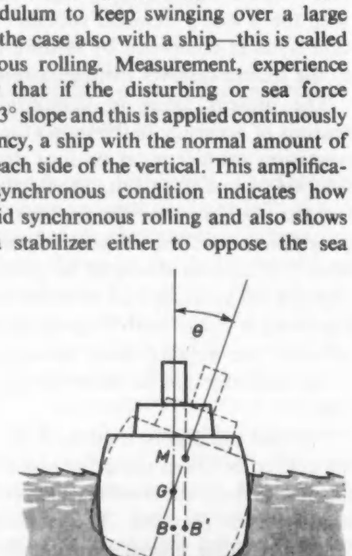


Fig. 1 A simple stability diagram which helps in understanding the basic problems of a ship's motion

Consider a vessel with normal damping in which a roll has been built up; let it be assumed that a calm now occurs—the rolling will gradually decrease at the rate of half amplitude in two complete rolls; the stabilizer should be arranged to quench the rolling more rapidly than this and in practice the increase in damping is of the order of 10 times the natural damping. Another case, that of a single large wave encountering the vessel is a fairly frequent occurrence and the order of rolling produced is not so large as with syn-

chronous rolling but may give the ship a movement of $\pm 12°$ from a $\pm 5°$ wave slope.

From the above the desirability and the scope available for an effective stabilizer is clearly seen. Measurement of ocean waves has shown that the effective wave slopes experienced vary from zero to 5° for sea conditions from calm to storm. Exceptional wave slopes up to 9° are believed to have been encountered but these are regarded as freaks not to be taken into account when designing a stabilizer—if they were it would be excessively large and expensive.

The frequency or period of encounter of the waves with the ship depends upon the speed and direction of the ship as well as on the speed, direction and length of the waves. Thus if the ship is steaming into a sea the frequency of encounter will be much higher than if steaming in the opposite direction and all frequencies between these limits are possible by altering the course of the vessel. Synchronous rolling may thus be obtained in the case of a large ship travelling roughly in the same direction as the waves (following sea), the rate of encounter of each wave with the ship being slowed down by the common direction of travel until it corresponds with the rolling period of the vessel. Synchronous rolling of smaller vessels occurs at other angles, the worst usually with the vessel broadside on to the waves.

Different attempts at stabilization

A number of methods have been used in attempts to find a satisfactory and practical ship stabilizer, and these have included water tanks, moving weights, large gyroscopes, water jets and various ship forms. They have not proved a success to judge by the small number of installations. The remaining method uses keels or hydroplanes in one form or another.

The usefulness of bilge keels for roll damping was early established, and they are normally fitted to vessels. The size of the keels is limited because they cause additional drag acting against the forward motion of the vessel and hence reduce the speed and increase the operating costs. Under the synchronous conditions in a sea with a 1° wave slope, a vessel not fitted with bilge keels might roll 12°, while with bilge keels as normally fitted the roll would be about 6°.

Fins or hydroplanes are arranged to produce a lift (or depression) due to their reaction with the water as the vessel proceeds forward. They can be effective only at or near the rated speed of the vessel; if designed for a range of speeds the installation has to be large to cover the low speeds and the operative fin angle must be limited for higher speeds. An example of a fin on a modern liner is shown in Fig. 2.

A number of designs of fin is possible—from the simple hydrofoil section of low aspect ratio to high efficiency types of fin with one or more flaps and high aspect ratio. Although the efficiency of the fin, that is its lift in relation to its size, can be varied considerably, the lift in relation to drag does not alter very much, and at the maximum angle (near to the stalling point) at which the fin is designed to work the drag is approximately a quarter of the lift. This means that in addition to the small auxiliary power required to operate the fin in the angular sense, a large amount of power is taken at full deflexion from the main propulsive engines to provide the drag associated with this device.

The roll damping obtained from the activated fins is of a different order from that of the bilge keels or passive fins. The synchronous rolling amplitude of a ship fitted with bilge keels is given above as 6 times the wave slope, whereas with activated fins the factor might be ½; thus the damping of the active fins is about 12 times that of the passive arrangement. The idea is not new—an early version is described in Patent No 19886 granted to Hiram S. Maxim in 1890: '. . . My invention is designed to prevent the rolling and pitching of vessels at sea . . . It would require a relatively small amount of force, if properly applied to the ship, to prevent or greatly diminish the rolling and pitching of the same. I accomplish the desired result in a convenient and advantageous manner by the employment of strong fins worked by hydraulic or other motor apparatus, the action of which is controlled by gravity or otherwise.'

In a later section more consideration will be given to the active fin method of ship stabilization.

Control equipment

The control of the stabilizer is vested in an equipment which consists of three distinct parts, the sensing unit or units, the initial amplifier, and the main power amplifier whose output operates the stabilizing or torque-producing mechanism.

The sensing unit. This can take several forms, the most simple of which satisfies the conception of roll damping only, in

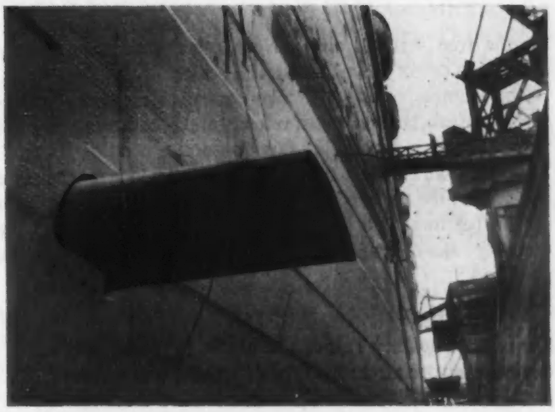


Fig. 2 The *Queen Elizabeth* is the largest ship to be fitted with stabilizing fins and this photograph shows one of the four fins (two on each side)

which case a rate- or velocity-sensitive gyroscope provides the main signal. This gyroscope measures the rolling velocity of the vessel and within limits gives a proportional signal which is obeyed by the stabilizer. Beyond this limit the stabilizer is working at full power and although the signal may increase, no further response is possible from the stabilizer. In order to make the damping more efficient, an anticipation device of sorts is sometimes added to advance the signal from the rate gyro so that the signal for the change-over of the sense of the stabilizer torque is early, thereby compensating for a lag in the larger later stages of the servo.

Numerous devices in addition to gyroscopes have been proposed for giving a more refined signal than that given by the rate gyro only, and these signals are combined to give an ideal signal to achieve the best possible stabilization. Such devices provide for measuring the false vertical (by simple or compound pendulums), measuring the height of the static head of the waves pressing against the vessel, measuring the translational acceleration of the vessel and/or the rolling acceleration. Also a vertical gyroscope can be used as a datum

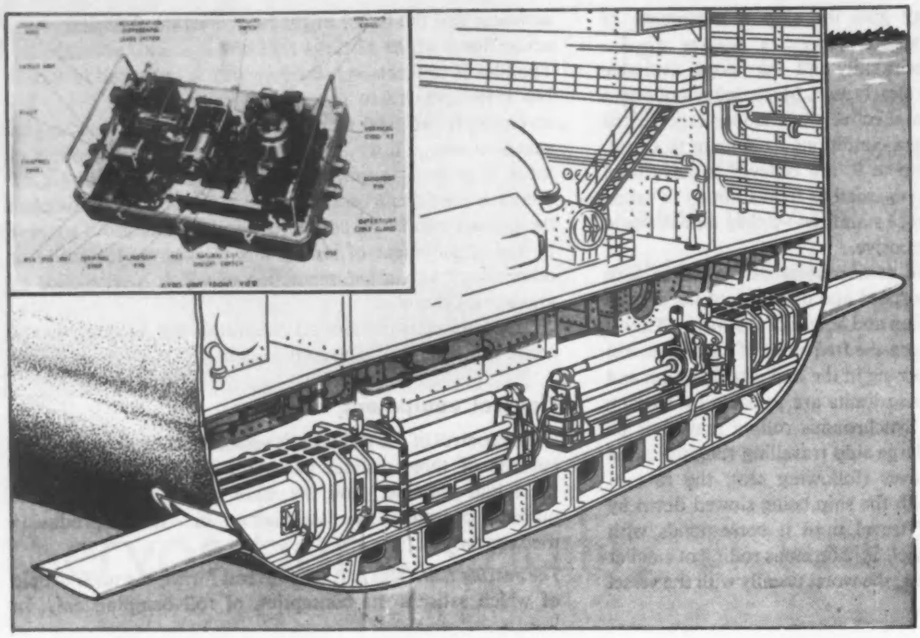


Fig. 3 A typical arrangement of the stabilizing fins in a ship with the fin operating and retracting gear mounted on the frame at the end of each fin box. The fin box is welded to the hull and is flooded when the ship is in commission. Inset is the gyroscope sensing unit

for the true vertical, and various other devices have been evolved to detect the mean list of a vessel.

For example, in one particular control (Muirhead compensated control), the roll angle, velocity and acceleration are used together with a natural list function and a position fin feedback; these all combine to produce a signal which is taken as a measure of the required stabilizing torque. In another system the lift (or torque) is measured by a strain gauge and is the quantity against which the combined sensing signal is balanced.

The amplifiers

The initial amplifier. This can be any of the commonly known devices appropriate to the type of sensing unit employed and capable of yielding an output suitable for the larger power amplifier.

For example the gyroscopes can operate the contact arm on a potentiometer energized with direct current; similarly the static pressure head units may operate potentiometers, and the combined signal may be taken to an electromagnetic relay or a set of contact segments controlling a Ward-Leonard or similar dynamo-electric amplifier.

Alternatively, electronic, magnetic, or transistor amplifiers may be used taking positional inputs from synchros, magnetic pick-ups, a strain gauge or the like, and controlling by the output from the amplifier a large moving-coil unit capable of operating a hydraulic valve.

A gyroscope measuring roll velocity or roll acceleration may operate one or more carbon piles by virtue of the torque it exerts, the output of which can be employed with further amplification to control the stabilizing means.

Another, and perhaps more direct, method uses Magslips (or synchros) connected by mechanical couplings to the sensing means and controlling the pilot valve of a hydraulic relay. The mechanical output of the hydraulic relay controls the larger hydraulic unit of the stabilizer.

The main power amplifier. The final stage of amplification depends on the type of stabilizer; for the moving-weight type hydraulic rams might be used with or without an amplification of the mechanical movement such as a wire rope and pulley system, alternatively the 'weight' may consist of an electric locomotive moving itself in accordance with the signals received and amplified by an electrical controller.

For water tanks and water jet stabilizers large pumps have to be controlled, while for other types of stabilizer a mechanical angular movement is required such as the positional control of a fin shaft, and conventional hydraulic or electrical servos may be adapted for the purpose.

Fin variations

The point should be made clear that a ship is not unduly stressed by fin stabilization. The aggregate torque produced by the fin or fins is such as to be able to tilt a vessel approximately 5° from the vertical in calm water. The force is not applied impulsively since it is regulated to be in accordance with the demand of the sensing unit and the maximum speed of operation of the fins is such that they will travel from full deflexion in one direction to full deflexion in the other direction in something like 10 to 15% of the period of roll of the vessel. Also it should be noted that the racking stresses on the superstructure of a vessel when it is stabilized are much less than on one which is freely rolling.

The arrangement of fins to achieve the anti-rolling torque required depends on many factors such as the internal layout of the ship, the duty which the vessel has to perform, its entry into harbour and the proximity or association with other vessels. Installations have been made with the number of fins varying from 1 to 8, and with different types of fin from the simple hydrofoil of low aspect ratio to the high efficiency type with high aspect ratio and flap.

A single fin can be installed either projecting from the keel downwards or projecting from the side where the bilge keel would normally be fitted. The single installation at one side does not seriously interfere with steering nor does it unbalance the vessel; it does, however, require a larger fin than would be needed if a pair were fitted, but an economy in space, weight,

and cost is made in that the operating equipment internal to the vessel is reduced to the absolute minimum. A disadvantage of the vertical single fin is that its radius of action from the centre of rolling is small, and consequently the fin must be larger than that required when fitted to the bilge line which is at approximately the maximum radius from the centre of roll.

The arrangement fitted in most vessels is a two-fin retractable equipment (see Fig. 3) and in order to reduce the space required internally for retraction and also the weight of the equipment, it is normal to use the flap type of fin, which gives a greater lift per unit of area (see Fig. 4).

For installations in vessels such as the Cunard 'Queens' a pair of fins of practicable size has not proved to be sufficiently large. Two pairs are used, and the four fins, although controlled in pairs, are each operated separately by hydraulic servo equipment. For an installation of the non-retractable type it is obviously desirable to keep the fins to the minimum outreach and within the rectangle formed by a vertical from the maximum beam and the horizontal through the keel. To achieve this a lower aspect ratio of fin may be used, together with an increased number of fins as required to give the necessary aggregate stabilizing torque. Since the fin is not to be withdrawn into the vessel, a flap type may not have any great advantage over the simple hydrofoil.

Many variations are practicable in addition to the above:

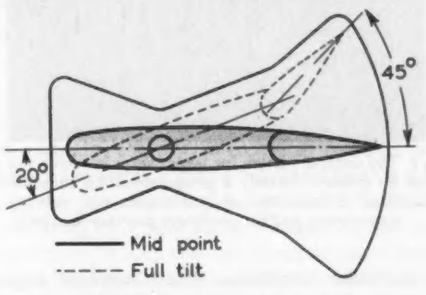


Fig. 4 The flap-type fin shown in Fig. 2 has a number of advantages over the simple hydrofoil, and the diagram shows its degree of movement

for example, fins may be disposed in a bi-plane or tri-plane assembly or they may be arranged in the form of an array in which a master fin is set in the vessel slightly ahead of a system of tail fins which are independently controlled internally to the vessel. The tail fins are arranged to tilt more than the master fin and give the effect of the high efficiency type by deflecting to a greater angle the water initially deflected by the master fin. All the above types of fin are based on a normal hydrofoil section mounted on a fin shaft projecting approximately at right angles to the skin of the vessel. Some further types are possible, for example, a plane or fin surface set at constant angle may be retracted in or out of the vessel according to the requirements of the control. In other words, the area exposed to the stream of water is varied by the control instead of the angle of the tilt. The sliding motion may in other variations be replaced by a rotary motion to achieve the same purpose. Local formations of the hull of the vessel may also be contrived to accommodate the fins better, achieving a more effective torque with a minimum projection.

With regard to methods of retraction, whilst in the Denny-Brown system the fins are normally arranged to push straight in and out, other arrangements are possible: for example they may be pivoted to swing in a horizontal plane into the side of the vessel; alternatively they may be folded up against the side of the vessel. No doubt other variations will appear as the art develops.

Practical equipment

I now turn to practical equipment. I have been associated with several systems of control, starting with a roll-velocity-operated contact system that provided on-off control only, this being superseded by a proportional control based on combinations of roll angle and roll velocity. The controls at present being fitted are of two types: one for small ships—say 300 tons or less, in which the fin angle control is proportional to roll velocity; and the other for larger ships (the compensated control previously referred to), in which the fin angle is proportional to an addition in appropriate proportions of roll angle, roll velocity, roll acceleration, fin positional positive-feedback and natural list. These controls will now be described in some detail, together with the hydraulic servos used for intermediate amplification and final fin operation.

In Fig. 5 is shown the schematic arrangement of the control system for small vessels. The sensing unit is the rate gyro (A) measuring the rolling velocity of the vessel; operating from it through suitable linkages is a differential lever (B) to the centre of which a sensitive hydraulic valve (C) is attached. It will be observed that the liner of this valve is oscillated by means of an eccentric (D) driven by the motor (M). The other function of the motor is to drive the oil pump (P) supplying oil through the valve to the relay cylinders (E). Suitable levers pivoted on the structure of the cylinders are arranged to reset the differential lever (B) and also to operate the output lever (F).

Up to this point the equipment described is contained in what is known as a gyro-controlled hydraulic relay, illustrated in Fig. 6. In one form it incorporates the single stage of amplification described and in another example, there are two stages of hydraulic amplification.

The output from the hydraulic relay is coupled generally by rod gearing, although an electrical link may be used under certain circumstances to replace the link (G), and operate a differential lever (H). From the differential lever the valve (J) is operated and controls the flow of oil from the motor driven pump to the final operating cylinder (K), which may be of the differential type shown, and is directly coupled to the fin shaft

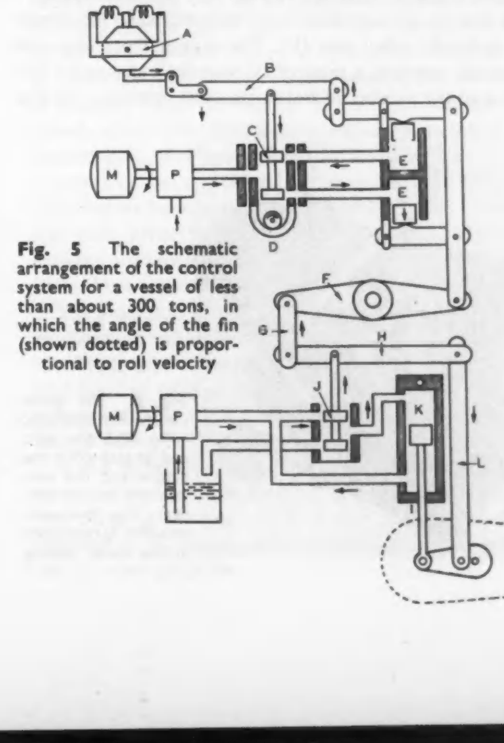


Fig. 5 The schematic arrangement of the control system for a vessel of less than about 300 tons, in which the angle of the fin (shown dotted) is proportional to roll velocity

operating lever to which a link (L) is also attached to reset the differential lever (H).

It will be observed that the two hydraulic systems are entirely separate. This has been found essential in order to keep the sensitive first stage of the hydraulic amplification clean enough to ensure reliable operation of the pilot valve system. This system is operated by a very small input force and therefore requires really clean oil to avoid mechanical interference between valve and liner due to foreign matter.

The corresponding diagram for the operation of the stabilizing fins in large ships is shown in Fig. 7. The sensing unit is shown in some detail, the essential controls being derived from the two gyroscopes, the pendulous one (A) giving an output of roll angle and the rate or velocity sensitive gyroscope (B) yielding first a roll velocity term and secondly, by differentiation, the roll acceleration.

The hydraulic relays are shown as blocks only; they consist, however, of the same units as indicated in the first part of Fig. 5, but without the gyroscope (A) shown in that diagram.

Stabilizing larger ships

Referring to the details shown in Fig. 7 it can be seen that the rate gyroscope (B) is coupled by a link to the differential lever (C). At one end of this is a geared up damping unit (D) and at the other end a lever (E) suitably pivoted and spring centred. The action of the mechanism is that for any constant acceleration, i.e. constant velocity of the deflexion of the rate gyro, the deflexion of the spring centred lever (E) is balanced against the drag of the damping unit. For constant rolling velocity the lever (E) is centralized and the disk of the damping unit is stationary.

Considering the application of a step impulse to the vessel, the immediate effect is that the rate gyro deflects rapidly. The damping unit holds one end of the differential lever (C) and a large deflexion of the spring-centred lever (E) results, giving a measure of the acceleration imposed.

Similarly for deceleration or acceleration in the opposite sense, the lever (E) is deflected in the opposite direction. If a simple harmonic motion is applied, the output from the differential arrangement is in practice sinusoidal and about 70° leading compared with the velocity, instead of 90°, which it should be ideally. Magslips are connected mechanically to each of the outputs—roll, roll velocity and roll acceleration—and the outputs are summated and transmitted to the hunter of the hydraulic relay unit (F). The output from this unit mechanically operates a number of Magslip transmitters (G) according to the number of follow-up units operating the fins

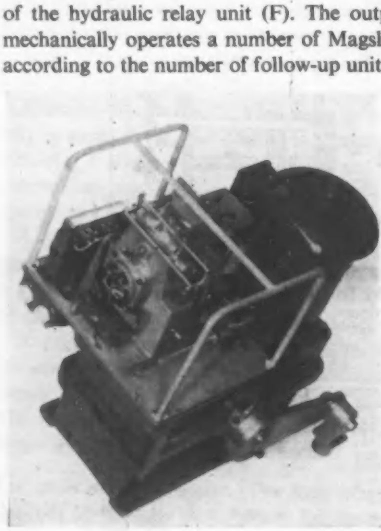


Fig. 6 The gyro-controlled hydraulic relay with the gyro and its pick-off in the centre and the output arm at the bottom. The hydraulic amplifier is contained in the lower casting

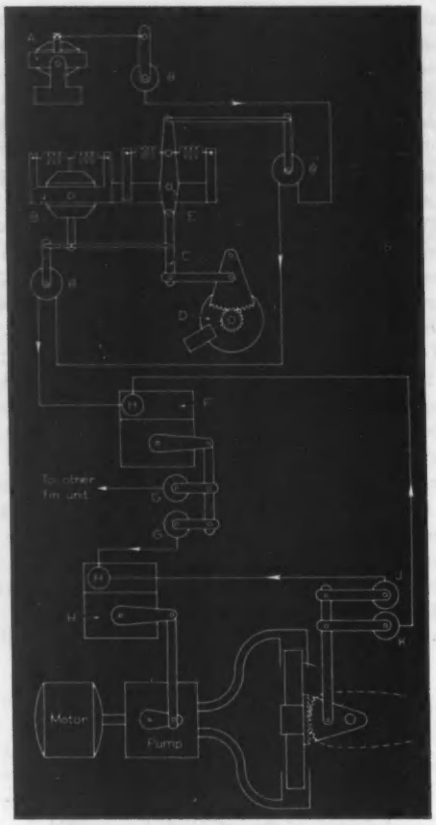


Fig. 7 The control system for larger ships in which the angle of the fin (shown dotted) is proportional to an addition in appropriate proportions of roll angle, roll velocity, roll acceleration and fin positional positive-feedback

in any particular installation. The transmitter is connected to a hunter in the hydraulic relay unit (H) the output of which controls the delivery of a variable delivery pump. The oil flowing from this pump is connected to a pair of hydraulic cylinders, the pistons of which are thereby driven according to the output of the pump both in velocity and sense, and the stabilizing fin geared to the combined piston is deflected and performs the stabilizing function, reacting with the slip stream of the vessel. Attached to the fin operating arm is a link operating a pair of Magslips (J) and (K).

It will be seen that the first of these is connected to the hunter in the hydraulic unit (H) and performs the function of resetting through the hydraulic relay unit the variable-volume pump. The second Magslip is connected to the hunter in the relay unit (F) and is used to give the positive positional feedback in the control referred to above.

Provision is also made in the control for operating the stabilizer according to the list of the vessel; the roll angle input is modified, by using the mean list as the datum instead of the true vertical. This is arranged by means of a servo, not shown in the diagram, following the roll but with a time-constant of the order of a few minutes; it results in a more economical use of the stabilizer since it is not being employed to counter a constant force such as may be present due to uneven loading of the vessel or a list due to a steady wind.

Some explanation of the reason for selecting the particular controls is perhaps appropriate. In the case of the smaller vessels the object was to produce the simplest possible control,

which is obviously damping of the vessel's motion. The control is therefore required to oppose the motion of the vessel whenever it occurs, and the sensing unit, namely the rate or velocity sensitive gyro measuring the velocity and being followed up proportionately by the fin deflexion, gives exactly what is required within the limits of stabilizing torque available. Some lag inevitably occurs in the operation of the rate gyro and the follow-up systems operating the fins, and compensation for some of this lag is achieved by fitting an anticipation device to the gyro. This takes the form of a damping and spring unit somewhat similar to the acceleration unit described in connexion with the larger control (see Fig. 7).

For the larger vessels the ideal being striven for is to hold the vessel, substantially preventing it from rolling, as distinct from merely damping the roll. It is therefore necessary to take cognizance of the incidence of a roll and operate the stabilizer to counter this as quickly as possible. Thus when a wave strikes a vessel the acceleration unit responds and operates the Magslip which gives a signal to the fin to counter the acceleration. If the stabilizer is not sufficiently prompt in action, a velocity will be built up and the velocity Magslip signal will then be added to the existing signal, giving an increment to the stabilizer force. Similarly as a roll angle builds up this signal is also added. The controls may therefore be regarded as operationally independent, the stabilizer responding to the sum of the controls at any given time.

Further study of the problem

Two special cases merit further examination, one is that of the ship being vertical and having impressed upon it an acceleration within the capacity of the stabilizer to counter; and the second is the case when, owing to larger sea forces acting upon the vessel, a simple harmonic motion is built up.

Taking the first case, the signal generated would cause the stabilizer to act to oppose the acceleration on the vessel, and if the sensitivity is such that the stabilizer neutralizes the sea force upon the vessel, the net signal generated by the sensing equipment will then indicate zero acceleration. This is obviously incorrect, since the fins would then be signalled to go to zero inclination and the force of the sea upon the vessel would be unopposed. To avoid this occurring a positional positive feedback has been instituted as shown in the diagram by Magslip (K). This injects into the control circuit a signal proportional to fin movement. If it represents 100% feedback, then the signal originally ordered is maintained and the vessel continues to experience no roll acceleration until the sea force changes. In practice, something like 70% feedback appears to give the best results. It will be appreciated that feedback is present whether the signal is due to acceleration, velocity or roll angle. For the two latter functions it operates to increase the sensitivity of the control.

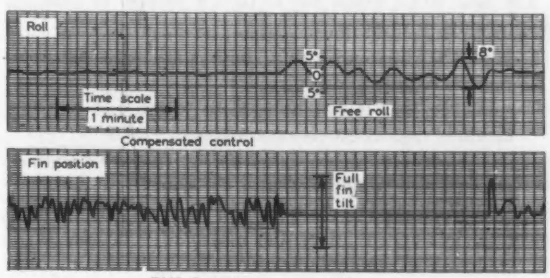


Fig. 8 A record of the motion of a vessel of 20 000 tons in a moderate sea. The lower trace indicates the movement of the stabilizer fins and the upper one the movement of the vessel. About half-way along the trace the stabilizer was switched off, whereupon it can be seen that appreciable rolling started

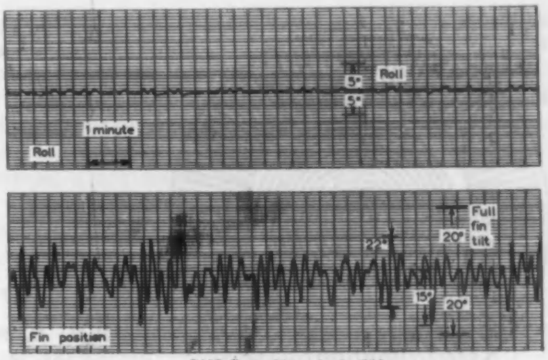


Fig. 9 The efficiency of the stabilizing equipment is well demonstrated in this trace, which was obtained with the largest class of vessel under rough sea conditions. The rolling is maintained within $\pm 1°$, when without the stabilizer it would have had peak values of the order of $\pm 15°$

Taking now a vessel in which simple harmonic motion of rolling has been built up, it is apparent that the best control which can be operated is a damping control with sufficient anticipation to keep the damping correctly in phase with the velocity of rolling. However, with simple harmonic motion present, signals from both the roll and the acceleration units will be present in the combined signal. These are not desirable but fortunately they are naturally in antiphase with each other and use has been made of this fact to make them cancel out. The acceleration function, however, is generally made a little larger than the roll angle function by appropriately selecting the sensitivity for the natural periodic rolling time of the particular vessel. The predominance of the acceleration in this way provides the necessary anticipation to the velocity function to compensate for the lag in the hydraulic servos operating the fins.

Examples of stabilization are given in the records of Figs. 8 and 9.

The future of stabilization

Experience on the installation and operation of stabilizers in over 2 million tons of shipping indicates that stabilization of ships has come to stay. For new passenger ships the stabilizer is regarded as almost an essential requirement, and in many instances it is considered worth while to install them in existing vessels having still a useful period of life. Other vessels, apart from the obvious use of the stabilizer in naval applications, have been so fitted for the better transport of fruit and of live cattle. Vehicle ferries and special ships such as ice breakers have also been successfully fitted. Consideration has been given to the installation of the stabilizer in oil tankers, where an economy may be expected by virtue of the better time keeping of the vessel fitted with a stabilizer.

The reduction of rolling has been found by experience on all classes of vessels fitted to be sufficiently effective to simplify the navigation; the captain can maintain his normal course and speed in spite of the weather without danger to the ship, whereas without stabilizers a reduction in speed and a change of course is often dictated by storm conditions.

It can be expected in the future that further refinements of control may be introduced but probably the major changes will occur in the mechanical details and fitting of the fins. Progress in the development of non-retractable and multiple fins is most probable.

ELECTRICAL TRANSDUCERS—3

by **R. E. FISCHBACHER, B.Sc., A.R.T.C., A.M.I.E.E.**
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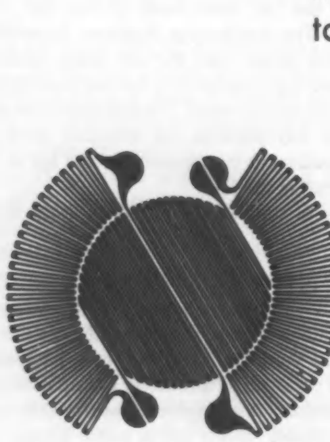
How to measure strain

The strain gauge is accepted by engineers as a valuable aid in tackling many difficult problems. Mr. Fischbacher discusses the requirements for an ideal strain gauge, and this leads on to the practical problems of available types



THE MEASUREMENT OF STRAIN HAS ALWAYS BEEN OF VITAL concern to the mechanical and the civil engineer. If it should appear to have gained in prominence in recent years, it is because the means of measurement has been vastly simplified and reduced in cost. The advent of the resistance strain gauge in cheap mass-produced form has made it possible to carry out detailed examination of strain distribution on structures and machines of all kinds under working conditions. The impact of this new facility upon mechanical design has been considerable in a field where large factors of safety had to be used, largely to allow for the effects of unexpectedly large stress concentrations. Most of this article will be concerned, therefore, with the resistance strain gauge.

STRAIN GAUGE REQUIREMENTS

The ideal strain gauge has to fulfil a number of exacting requirements. It must be:

a. highly sensitive to strain, both static and dynamic, preferably only in one direction
b. small, so that it can be used to locate and measure localized high stress concentrations
c. independent of other variables such as temperature, pressure and humidity
d. readily attached to the work and when attached impose negligible constraint on the measured structure
e. lend itself to remote indication
f. be reproducible and cheap

The ideal instrument is rarely encountered in practice, and here is no exception. Yet the bonded wire or foil resistance strain gauge goes a long way toward meeting the requirements outlined above.

RESISTANCE STRAIN GAUGES

Almost a hundred years ago Kelvin noted the change of resistance of a wire under stress. Yet only in recent years, largely since the last war, has the technique been perfected and the resistance strain gauge put to work in its present form.

The most usual form of the gauge is that of a grid of fine wire or foil (of the order of 0·001 in. dia), firmly held in a suitable carrier which in turn is cemented to the strained member and is subjected to the same strain as the member. The strain causes a change of resistance which, within certain limits, is proportional to the strain.

Strain is defined as fractional change of length, and the relationship between strain and resistance change is usually called the gauge factor. The gauge factor is therefore

$$F = \frac{\Delta R}{R} \cdot \frac{L}{\Delta L}$$

The gauge factor varies with the type of wire used, but with those in most common use it is generally in the region of 2. The gauge factor is inherently a function of the material of the wire, but can to a small extent be affected by the cement in which the wire is set if this does not transmit all the strain to the wire.

The resistance of a single gauge is usually in the region of 50-120 ohms but resistances up to 2000 ohms may be encountered. The current varies with the type of gauge and may range from 10 mA up to $\frac{1}{4}$ A according to circumstance and mode of usage.

In America the form of construction has principally been that of a wire grid set in cement between two layers of thin paper for insulation. The type of cement varies according to temperature requirements—for example, phenolic resins for the middle temperature ranges, and ceramic cements for very high temperatures. The type of wire depends on whether static or dynamic strains are to be measured. Where static strains are involved, low temperature coefficients are imperative, but where dynamic strains only are to be measured the relatively slow changes of gauge resistance due to temperature changes are not significant, and wire materials having a higher gauge factor can be selected with less regard to temperature coefficient.

The etched foil strain gauge was developed in this country. Here the grid is etched from a sheet of metal foil of closely controlled thickness. By carefully controlling the process a very reproducible gauge is achieved. Its chief advantages are that the rectangular section leads to better adhesion to the strained member, and the larger surface area increases the heat dissipation and therefore the current carrying capacity of the gauge. This effectively increases the sensitivity for a given gauge resistance. The gauges are mounted in a thin lacquer with good insulation resistance and with good mechanical properties.

The form of a typical gauge is shown in Fig. 1.

Mounting the gauge

The operation of the gauge is dependent on its close bonding to the strained member. This is achieved by using suitable cement, preferably that recommended by the gauge manufacturer. The work surface is first thoroughly cleaned and an even layer of cement is applied. The gauge is then carefully laid on the cement, with its axis aligned with the direction in which strain is to be measured, and pressed carefully down on to the cement layer taking care to trap no air. It is usually recommended that a force of 2–10 lb/in^2 be applied to the gauge while the cement dries out. The drying may be accelerated by gentle heat but the cement should be allowed at least 6 hours, and for long-term stability up to 24 hours, to dry out thoroughly.

Where moisture is likely to cause insulation problems it is advisable to protect the gauge. This can be done by recommended protective coatings, or by a suitable cover, which may contain a moisture absorbent material.

Where the highest accuracy is required several strain cycles, and temperature cycles where appropriate, should be carried out before measurements are made.

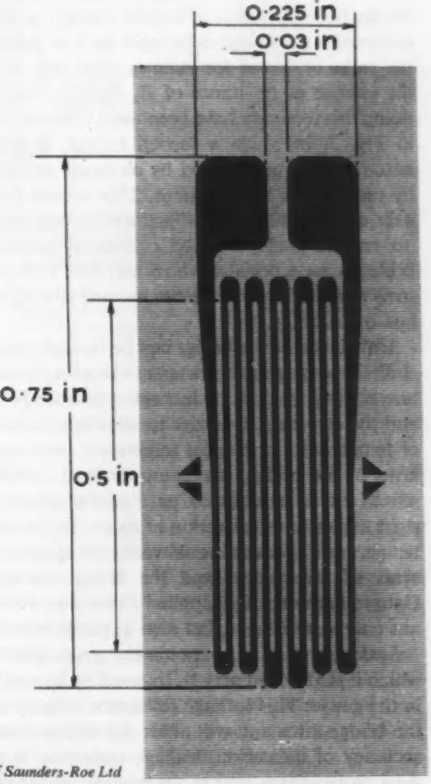
Strain performance

At first sight it might appear that the resistance strain gauge can be used only to measure tensile stresses. However, the wire has a very small cross-section and adhesion to the cement is sufficient to cause compression of the wire without buckling. Extension or compression of the gauge up to the extent of 3% can be achieved without disruption of the cement bond, but beyond a strain of 0·7–1·0% most gauges alter their calibration. With a careful technique the resistance strain gauge can detect strains of the order of one micro-inch per inch, i.e. 1×10^{-6}.

Strain gauges are normally slightly sensitive to strains at right-angles to the normal strain axis. The mount of this cross-sensitivity is usually less than 2% of the sensitivity on the main axis.

Strain bridges

The very small change of resistance in the strained gauge can best be measured by a bridge technique. In the basic arrangement of Fig. 2 the bridge is balanced at zero strain. The



Courtesy of Saunders-Roe Ltd

Fig. 1 The foil strain gauge was developed in this country and has a number of distinct advantages over those formed of a grid of fine wire

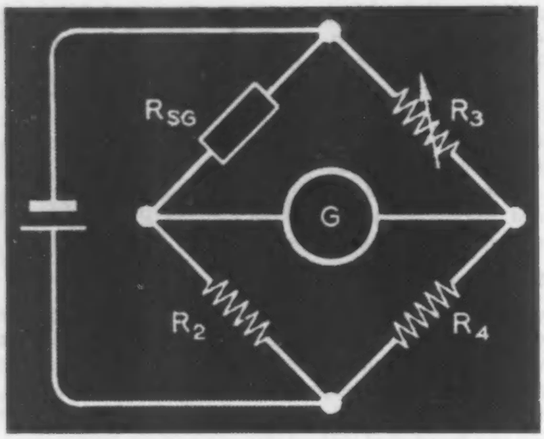


Fig. 2 The basic arrangement for a bridge to measure the very small change in resistance of a strain gauge. The bridge is balanced at zero strain

resistance change caused by strain unbalances the bridge and causes a current proportional to strain to flow through the galvanometer (G). The strain sensitivity of the simple bridge is limited only by the current which can be carried by the strain gauge and by the sensitivity of the galvanometer. In practice more sophisticated bridge arrangements are often used. The bridge may be fed by an alternating voltage, and the galvanometer replaced by an amplifier and detector, giving greater sensitivity.

The out-of-balance voltage of the bridge is dependent not only on strain, but on supply voltage. Since at balance the bridge is independent of supply voltage, greatest accuracy is achieved if the bridge is brought back to balance by adjusting the value of one of the balance arms, say R_3 and reading off the change of resistance of R_3 directly. Various methods of doing this remotely have been used. One such system is shown in Fig. 3, in which a second bridge, remotely situated, is automatically unbalanced by an equal and opposite amount by means of a servo system. This system has an advantage over a straightforward adjustment of one bridge arm in that no remote leads need be connected across an individual bridge arm—a practice which may lead to the introduction of stray potentials or resistances into the circuit, with consequent loss of accuracy.

Unbalance of the bridge can be brought about not only by strain, but by gauge resistance variation caused by temperature change, or even by leakage resistance between the gauge and the structure. In order to eliminate or reduce the effects of temperature it is usual to connect two gauges in different arms of the bridge, one being strained, and the other being affixed to an unstrained part of the same member, or at right angles to the direction of strain. In this way variation of temperature produces equal variation of resistance in the two arms of the bridge, and the bridge remains in balance. Gauges are normally supplied in batches which are matched not only in resistance, but also in temperature coefficient.

Leakage resistance between the gauge and the member to which it is attached may be lowered by humidity or by a fault in the gauge. This leakage resistance is likely to shunt one of the bridge arms and will affect the bridge reading. For good accuracy of indication, leakage resistance should be greater than 10 megohms, and in some cases, where high accuracy is required with higher resistance gauges, may have to be as much as 1000 megohms.

Siting the gauge

The siting of gauges can be arranged to take account of particular stresses. For example if the two gauges on the cantilever in Fig. 4 are connected in the measuring bridge as shown only flexural strains will be measured. The tensile strain caused by force *F* will be common to both gauges and will not cause unbalance, whereas the flexural strain caused by load *W* causes compression of one gauge and extension of the other, resulting in a bridge unbalance proportional to flexural strain. Temperature effects are here compensated by the use of two gauges. On the other hand, if it is required to measure the total tensile strain, the lower compensating gauge must be unstrained.

Gauge forms

The most usual simple form of the gauge is a grid similar to that shown in Fig. 1. A number of other forms are also fairly standard. These include sets of gauges mounted at right-angles and at angles of 60° as in Fig. 5. For use on diaphragms where radial or circumferential strains, or both, are to be measured, strain gauges such as the three shown at the beginning of the article can be used. (The three strain gauges appear by courtesy of Saunders-Roe Ltd.) Yet other types, for example for torsion measurement, are produced for special purposes.

Gauges for high temperatures

Development of high speed airframes, aero engines and nuclear reactors has produced a growing requirement for

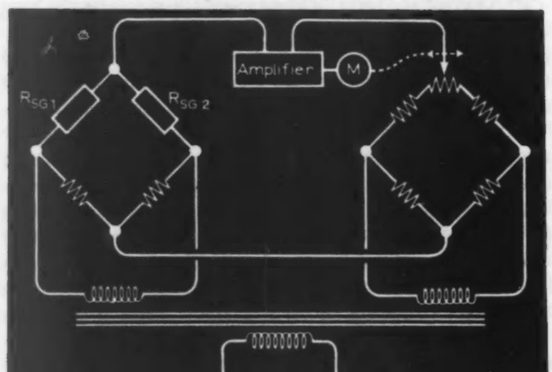


Fig. 3 A more complex bridge which leads to greater accuracy than the bridge of Fig. 2

strain gauges to work at high temperatures. Strain gauges capable of operating at 1000 deg C will undoubtedly be required although most of the current requirements are met by gauges capable of operating in the region of 500–600 deg C. At such temperatures the chief problems are those of a suitable backing material for the gauge and of a cement which will perform satisfactorily. Attention has also to be paid to the metal used for the grid element. Asbestos paper backing has been used and various ceramic cements developed to make the high-temperature gauge possible. In some cases the backing is stripped off and the grid is sealed between two layers of ceramic cement. Considerable research is still being devoted to the improvement of high-temperature gauges and to extension of the temperature range.

Static and dynamic strain

The measurement of static strain is generally more difficult than that of dynamic strain. When static or slowly varying

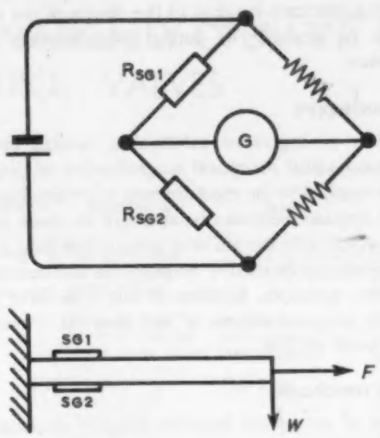


Fig. 4 Two strain gauges fixed on a cantilever for measuring flexural stress, and their connexion in a bridge circuit

strains are being measured, the inherent static stability of the gauge and bridge must be good. In particular, the temperature coefficient of the gauge material is important since any bridge unbalance due to variation of temperature will be indicated as a strain. Even when compensating gauges are used it is advisable to use gauges of low temperature coefficient for measuring static strain.

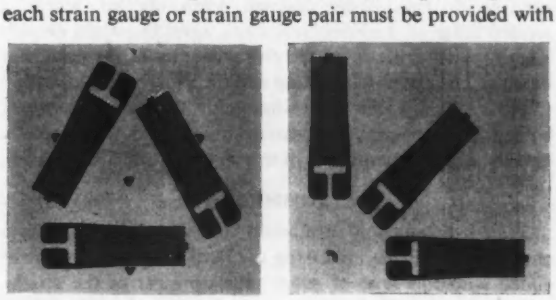
When measuring dynamic strain, slow variations of strain indication can be discarded by the detector and only variations which occur at the frequency of the strain accepted. Materials which give a higher gauge factor can therefore be employed despite higher temperature coefficients. Greater sensitivity can thus be obtained.

For dynamic strain measurement it is also important that the gauge should not be subject to changes due to fatigue. Materials which meet this requirement are used in gauges supplied for measurement of dynamic strain.

Up to about 100 c/s dynamic strain records can be obtained on high-speed strip paper recorders. Above this frequency they must be observed on an oscilloscope, where they can be photographed if required.

Multiple installations

The cheapness and simplicity of the resistance strain gauge lends itself to detailed investigation of structural or machine performance, usually involving the simultaneous measurement of strain at a number of points. In order to be able to do this various arrangements have been developed. In general each strain gauge or strain gauge pair must be provided with



Courtesy of Saunders-Roe Ltd

Fig. 5 Two ways of arranging strain gauges

its own bridge elements. This permits each bridge to be set up in balance before the strain is applied. The outputs of the various bridges are then switched in turn either manually or automatically to a common detector which detects the unbalance due to strain. Where two or more gauges must be examined simultaneously there is no alternative but to provide a complete bridge and detector unit for each gauge.

Transducers using resistance strain gauges

Its simplicity and ruggedness has led to the application of the resistance strain gauge to transducers in which strain is caused by the stimulus which is to be detected.

In the load cell, shown diagrammatically in Fig. 6, the application of the load causes strain in the vertical cylinder. The strain is proportional to the load, and is indicated by the resistance strain gauge bonded to the inner surface of the load-bearing cylinder. In a similar manner torque cells have been constructed.

Pressure transducers based on the use of resistance strain gauges to determine the strain in a diaphragm have also been produced, sensitive in the range of pressures from a few to several thousand lb/in^2.

OTHER METHODS OF STRAIN MEASUREMENT

Apart from the resistance strain gauge, which has been dealt with at some length because of its widespread application, a number of other methods are available. Essentially

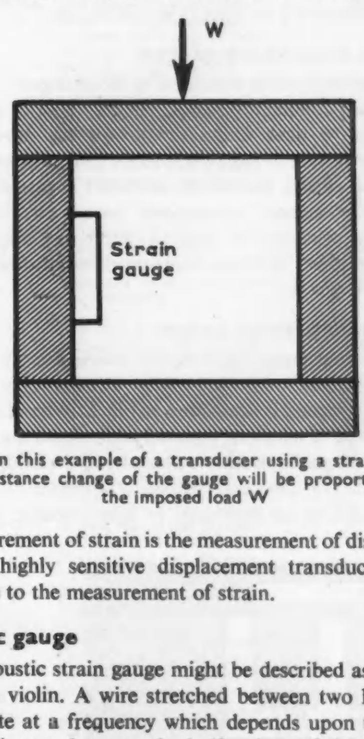
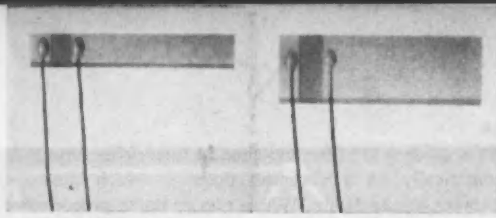


Fig. 6 In this example of a transducer using a strain gauge the resistance change of the gauge will be proportional to the imposed load W

the measurement of strain is the measurement of displacement and any highly sensitive displacement transducer will be applicable to the measurement of strain.

Acoustic gauge

The acoustic strain gauge might be described as the strain engineer's violin. A wire stretched between two knife edges will vibrate at a frequency which depends upon the tension and the distance between the knife edges. If the knife edges are attached to the strained member, strain will cause an increase in tension of the wire. The increase in tension causes an increase in the frequency of vibration proportional to the square root of the strain. The modern acoustic strain gauge is not plucked or transiently excited, but is electrically kept in oscillation by a maintaining circuit, and the frequency of oscillation is electrically determined. Strains of 1×10^{-6} can be detected. Highly stable acoustic strain gauges have been constructed to determine long term structural strain changes and good results have been claimed.



Courtesy of Saunders-Roe Ltd

Fig. 7 A piezo-electric strain gauge is only useful for determination of dynamic strains at frequencies above about 20 c/s

Piezo-electric strain transducers

Piezo-electric transducers have the property of developing on the face of the transducer element a charge which is proportional to strain. Since the charge leaks away fairly rapidly the piezo-electric strain gauge is useful only for determination of dynamic strains at frequencies above about 20 c/s.

Currently the most useful material is barium titanate because of its high strain sensitivity and low impedance, but the material depolarizes at about 100 deg C and should not therefore be used in conditions much above 70 deg C. For higher temperature applications quartz can be used.

A thin wafer or bar of the material is cemented directly to the strained member, and the voltage from the element is displayed on an oscilloscope or a high-speed recorder. The element, which may be as small as 0·125 × 0·1 × 0·01 in. is almost equally sensitive to strain in either axis. An output as great as 0·1 V for strain of 1×10^{-6} may be obtained. A typical element [illegible] in. long is shown in Fig. 7.

Variable capacitance gauges

Displacement can be measured by the change in capacitance between two conducting plates, but this type of gauge does not appear to have found favour for the most sensitive measurement, largely because it tends to be affected by stray capacitance effects. Recent development suggests that more reliable displacement transducers based on the variable capacitance principle are able to detect displacements of a few micro-inches without being unduly affected by stray capacitance effects.

Variable inductance gauges

Variable reluctance displacement gauges are often used for the measurement of large strains. The basic principle on which most depend is illustrated in Fig. 8. When the movable element made of magnetic material is displaced the reluctance of the two magnetic circuits is altered and the bridge becomes unbalanced. The unbalance voltage is amplified and detected, giving an output proportional to displacement. Where the greatest possible care is taken in the design of the transducer it should be possible to detect displacements of a few micro-inches.

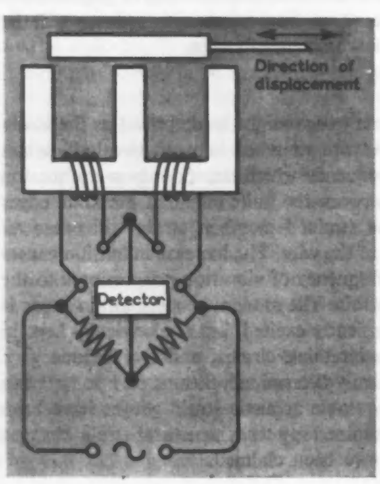


Fig. 8 Variable inductance strain gauges are often used for the measurement of large strains

Extensometers

A variety of ingenious mechanical devices designed to provide mechanical or optical magnification of displacement have been applied to the measurement of strain. For example, the strain displacement can be arranged to cause rotation of a mirror which with the aid of a spot or line light source and optical system can be used to magnify the displacement on the optical lever principle. Systems of this type have been constructed to measure strains of less than 10^{-5} over a gauge length as small as ½ in.

Optical methods

The use of an optical lever to magnify displacement has been mentioned above but such an optical system is really only an adjunct to a basically mechanical device. A technique which is more truly optical is that of the moiré fringe system. If two finely ruled gratings with the same number of lines per inch are superimposed with a small angle between the lines, a series of alternately light and dark fringes appear at right angles to the rulings of the grating, as in Fig. 9. Displacement of the gratings in a direction normal to the grating lines causes the fringes to shift in a direction at right-angles to the displacement. Displacement of the gratings by one line spacing causes fringe displacement by one fringe spacing.

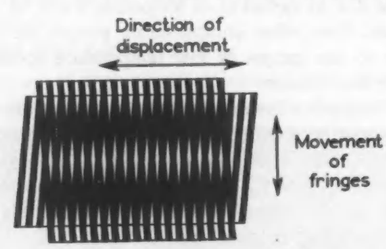


Fig. 9 Moiré fringes provide an optical method of measuring displacement

By using gratings with as many as 25 000 lines per inch displacements of a few micro-inches can be measured.

Brittle coatings

As an adjunct to the measurement of strain it is often necessary to determine at what points in a structure the strain exceeds a given level. Brittle lacquers or waxes have been used to do this. These coatings when applied within a limited range of thickness will crack when the strain exceeds a level which depends on the characteristics of the particular coating. The extent of cracking and the location and direction of the cracks will indicate at what points further measurement by strain gauges should be carried out. Cracks will normally develop only when strain is in the region of $500 - 700 \times 10^{-6}$.

SUMMARY

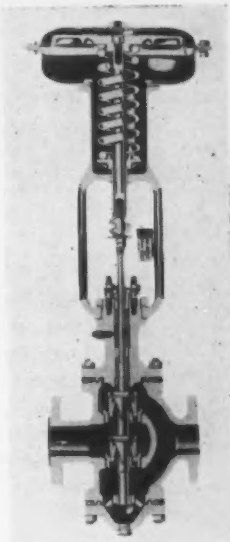
The cheapness and availability of the resistance strain gauge has led to its increasing use, and the techniques associated with this type of gauge take up most of the article. Mounting and siting of the gauges and the electrical circuits used as detectors are described, both for static and dynamic strain measurement. Mention is made of the use of the strain gauge in transducers. The article ends with a review of the alternative methods of strain measurement.

CONTROL 6 SURVEY

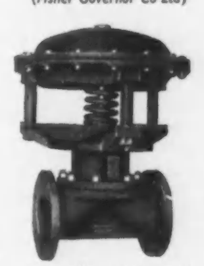
PNEUMATICALLY-OPERATED DIAPHRAGM CONTROL VALVES

These valves are precision instruments which have many applications in process control, and it is interesting to note that the four largest ranges are of American origin.

MANUFACTURER	DESCRIPTION	SIZES	VALVE BODY	OPERATING PRESSURE RANGE	REMARKS AND SPECIAL FEATURES
J. Blakeborough & Sons Ltd *Tick* **No 149** *on reply card*	Hammel-Dahl series B3000 globe valves	½ to 1½ in. screwed ¾ to 16 in. flanged	Standard—cast iron, cast steel, bronze	Primary service ratings cover ASA standards up to 600 lb/in²	Optional features are fluon packing, packless bellows seal, a finned bonnet, extension neck bonnet, jacking screws, reverse-acting superstructure, handwheels and valve positioner. The series B3000Q consists of 3-way valves. The series B4000 valves are designed for sensitive regulation, where it is permissible for the controlling fluid to come in contact with the diaphragm. The series B7000 barstock angle valve with solid plug is similar to the Microflo pattern. The Minor series provides a range of small diameter control valves for use where maximum sensitivity is not essential. No provision for positioners. A still smaller range is the Midget series, available with a globe body only, and having a performance similar to the Minor series
	Hammel-Dahl series B7000 barstock angle valves (Microflotype)	½, ¾ and 1 in. with screwed connexions	Standard—carbon steel or stainless. Others available	Up to 3000 lb/in²	
	Hammel-Dahl series B7000 Venturiflo angle valves	1 to 8 in.	Carbon or stainless steel, chrome molybdenum, or special alloy	All ASA standards up to and including 1500 lb/in²	
	Hammel-Dahl series B4000 pressure loaded, balanced valves	½, ¾, 1, 1½ in. screwed. ¾, 1, 1½, 2, 2½, 3, 4, 6, 8 in. flanged	Cast iron or cast steel	Up to 250 lb/in² on valve body inlet	
	Hammel-Dahl series B6000 butterfly valves	In all regular sizes from 3 to 30 in. bare	Cast iron or cast steel	Up to 225 lb/in² gauge at 100° F for cast steel	
	Hammel-Dahl series BM7000 barstock angle type	Screwed (only) ⅜, ½, ¾ or 1 in. API or BSPT	Mild steel, bronze, stainless or any bar material	Up to 3000 lb/in² at 100° F according to material	
	Hammel-Dahl series BM3000 globe type control valves	Screwed ⅜, ½, ¾ or 1 in. API or BSPT. Flanged ½, ¾ or 1 in.	Cast iron, bronze, cast steel or stainless steel	Up to 1200 lb/in² at 100° F, according to material	
Crosby Valve and Engineering Co Ltd *Tick* **No 150** *on reply card*	Mason Neilan control valves 10 000 series	¾ to 2 in. screwed. ¾ to 6 in. flanged	Globe standard—cast iron and cast carbon steel.		All 10 000 series bodies and plugs are reversible.
	Mason Neilan percentage piston control valves	½, ¾, 1 in. screwed or flanged	Bronze, stainless steel, forged steel, cast steel, cast iron	Highest of series is up to 3000 lb/in² at 100° F	Suited for throttling control. Reverse motor available.
	Mason Neilan high pressure control valves	1, 1½, 2 in. screwed	Forged or cast steel	Forged steel angle type 300, 600 lb/in² at 232° C	Designed specifically high pressure and/or high pressure drop service
	Mason Neilan 700 series angle control valve	1—6 in. flanged	Cast steel	Up to ASA 1500 lb	Designed for severe operating conditions
	Mason Neilan small flow control valves	½ in. screwed ends	Globe or angle, forged stainless steel	Up to 6000 lb/in² at 230° C	Compact valves for close control of extremely small flows
	Mason Neilan 3-way control valves	¾ to 2 in. screwed ¾ to 10 in. flanged steel. 1 to 10 in. flanged iron	Globe. Standard—cast iron and cast carbon steel.	Up to 600 lb/in² depending upon material	Commonly used for combining or diverting service
	Mason Neilan Saunders control valve	½ to 3 in. screwed ends. ½ to 6 in. flanged ends	Cast iron—lined, if required, with rubber, glass or lead	Cast iron ASA class 125	Designed for throttling or on-off control heavy liquids, or liquids having solid particles in suspension
Fisher Governor Co Ltd *Tick* **No 151** *on reply card*	A, AR (single/double port globe)	½ to 2 in. screwed. 1 to 16 in. flanged	H.T. iron, carbon and stainless steel	Highest is 1440 lb/in² at 40° C	Special valves can be supplied for pressures up to 30 000 lb/in² and temperatures up to 1200° C. Valve positioners, hand jacks, manual operation, reduced size inner valves and a range of other accessories can be provided for most types. There are also angle bodies, three-way bodies, butterfly valves of various sizes and ratings.
	D (single port globe)	1, 2 in. screwed, flanged	Carbon steel or stainless	6000 lb/in² at 40° C (stainless)	
	DA (single port angle)	1, 2 in. screwed, flanged	Carbon steel or stainless	6000 lb/in² at 40° C (stainless)	
	G–GR (single port globe)	½ to 2 in. screwed	Bronze or stainless steel	150 lb/in² at 190° C	
	H–HR (single/double port globe)	1 to 8 in. flanged	Carbon steel or stainless	3600 lb/in² at 40° C	
	HD (single port globe)	1 and 2 in. welded ends	Carbon steel or stainless	6000 lb/in² at 40° C	
	HH (double port globe)	1 to 4 in. welded, flanged	Carbon steel or stainless	6000 lb/in² at 40° C	
Foxboro-Yoxall Ltd *Tick* **No 152** *on reply card*	Stabilflo control valves	½ to 12 in.	Standard—cast iron, cast carbon steel, bronze. Others on application		Three-way valves, handwheels, positioners and a number of accessories
Saunders Valve Co Ltd *Tick* **No 153** *on reply card*	Saunders diaphragm operated valves	½ to 8 in. flanged	Wide range of available materials		Available as pressure closing, high pressure closing or pressure opening type. A valve positioner can be fitted for precise control
Taylor Controls Ltd *Tick* **No 154** *on reply card*	Hi-flow control valves	½ to 2 in. screwed ends	Cast bronze	Up to 250 lb/in²	Low pressure drop for a given flow. A positioner can be fitted



The position of the valve in the controlled fluid is determined by the input signal pressure which is admitted to the diaphragm at the top (*Fisher Governor Co Ltd*)



A solidly constructed valve which may be obtained with a rubber, glass or lead lining (*Saunders Valve Co Ltd*)

For accurate operation these valves must be finished to very fine limits (*Crosby Valve and Engineering Co Ltd*)

The final instalment deals with more realistic simulation and closes with a quick look into the future

Analogue simulation in system design

by **R. J. A. PAUL, B.Sc.(Eng.), A.M.I.E.E., A.M.I.Mech.E.**

Deputy Head of Department of Aircraft Electrical Engineering, College of Aeronautics, Cranfield

2.3.4 Direct simulation approach

This technique (*12*) is an extension of the transfer function approach in that each individual element of a component block is simulated, thus giving a one-to-one correspondence between simulated elements and the real elements. For example an inductor inductance L may be simulated by an integrator with a coefficient $1/L$, the input to which is a representation of the voltage across the inductance. The output voltage of the integrator represents the current in the inductance. A few simple illustrations of this representation are given in Fig. 10.

In applying this technique it is only necessary to use the simplest fundamental laws of mechanics or electrical circuits, i.e. force-mass and voltage-current relationships.

The direct simulation of the position control system is shown in Fig. 9. A voltage representing $-\theta_i$ forms one input to adder 1. It is assumed that a voltage representing θ_o is available and this forms the second input. The transfer function of adder 1 is $-K_1$, i.e. the transfer function of the input and output potentiometers with a sign reversal. The amplifier of Fig. 5 is represented by adder 2 with a transfer function $-K_2$, and input voltages as in the actual system corresponding to $K_1(\theta_i - \theta_o)$ and $-K_5p\theta_m$. The output voltage from computing unit 2 therefore represents $-V_f$. The net voltage across the field inductance of the motor is $V_f - I_fR_f$. Thus the field circuit is represented by computing unit 3 in which voltage representing $-V_f$ and $+I_fR_f$ are the inputs, giving an output voltage representing I_f. The time constant of integrator 3 (R_3C_3), is made equal to L and the coefficient of the potentiometer is set to R_f.

The torque output from the motor is K_3I_f and if $K_f < 1$, it may be represented by the potentiometer shown in the simulator block for motor and load. The net torque acting on the combined inertia J of the motor and load is $K_3I_f - fp\theta_m$. Thus integrator 4 (with a time constant $R_4C_4 = J$), and input voltages representing K_3I_f and $-fp\theta_m$ respectively, forms the direct simulation of the motor load combination. The output voltage of integrator 4 therefore represents $-p\theta_m$ and the voltage $-fp\theta_m$ is obtained by means of the potentiometer of coefficient f, as shown. The linear gearbox is simulated by a potentiometer having a transfer function $1/n$, thus giving an output voltage corresponding to $-p\theta_o$. The latter voltage is integrated to give θ_o. The tachometer circuit is represented by a potentiometer fed from the output of computing unit 4. The output from this device is set to $-K_5p\theta_m$ and this voltage is fed back to form one input to adder 2 as originally assumed. The voltage output from integrator 5, representing θ_o, is fed back to one input of adder 1 to fulfil the original assumption. The simulation is now complete. It should be noted that no mathematical equations have been used other than the simple relationships expressed in Fig. 10. In addition there is a direct correspondence between simulated and real components.

2.4 Consideration of non-linear effects

A more realistic model of the simple systems shown in Fig. 5 would include such non-linear effects as amplifier saturation, backlash in the gearbox, static friction etc. Results from a simulator study of the linear model should correspond to typical analytical results, within a few per cent. If this correspondence is obtained, a more realistic simulation may

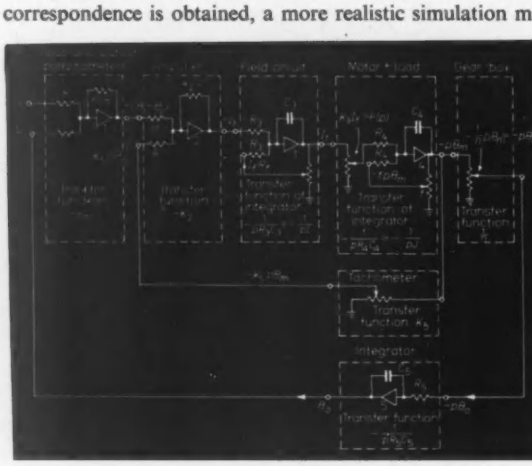


Fig. 9 The direct simulation of each individual element of the simple feedback control system leads to this computing circuit

be set up with confidence. The introduction of the simple non-linear effects above results in a tedious and difficult analytical study and it is at this stage that the simulator technique proves to be of most value, as the introduction of the simulated non-linearities do not present much trouble.

The methods of performing some simple typical effects are illustrated in Fig. 11. Methods of dealing with more complicated functions are given in (*8*) and (*9*).

In the design of the control system the labour involved in analysing the relevant equations, in many cases, restricts consideration of combinations of variables. One advantage of the simulator is that the particular significance of each non-

linearity over a range of operating conditions may be investigated. Again in many systems non-linear compensating networks may prove to be of value and these are easily introduced into the simulator.

It should, however, be borne in mind that the simulator cannot think for itself and results obtained have to be scrutinized with the utmost care. Efforts are usually made to have at least one analytical result for a particular set of conditions, for comparison purposes. The non-linearities discussed are relatively simple and it will be realised that the simulator technique may be extended to much more elaborate systems. A typical example is the simulation of dynamic performance of the nuclear power plant illustrated in Fig. 12.

The system comprises two main interacting loops. The reactor, circulating pump and heat exchanger, form the primary loop, whilst the secondary loop essentially consists of the heat exchanger, turbine, condenser and feed-water pump. The equations describing the performance of each part of the system are highly non-linear and consist of functions of severable variables.

The simulator technique is now being used extensively in these studies (*13*, *14*, *15*), and one of its overriding advantages is its use in the understanding of the rapidly developing science of nuclear kinetics.

2.5 Introduction of real components

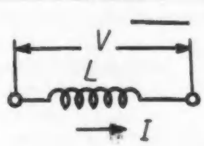
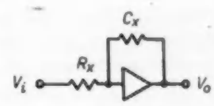
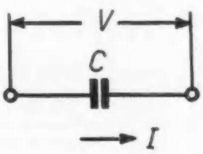
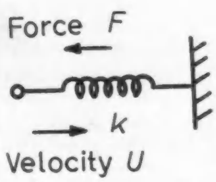
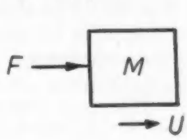
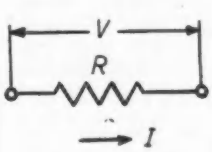
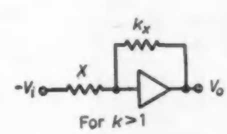
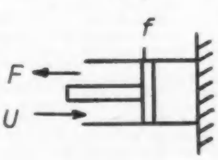
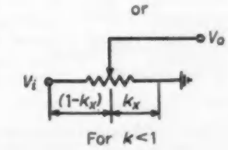
At the start of a project design little if any of system hardware is available. However, as an understanding is obtained of the individual specifications parts may be manufactured. As these become available they may be included in the simulator loop to give a more realistic simulator and to check their performance under dynamic conditions. For example, non-nuclear components may be tested by coupling them into the simulation of the system illustrated in Fig. 12.

3. FUTURE TRENDS IN SIMULATOR TECHNIQUES

As outlined in this paper the analogue computer has proved to be an extremely useful tool in the synthesis and design of control systems. For some applications, however, there are several drawbacks to its use, owing to limited accuracy, restricted versatility, reliability, etc.

The limited accuracy may become significant in the simulation of large-scale problems particularly with regard to

Fig. 10 The direct simulation technique shown in these diagrams is an extension of the transfer function approach illustrated in Fig. 4, in that each individual element of a component block is simulated, thus giving a one-to-one correspondence between simulated and real elements

	Element		Simulated Element	
Description	symbol	formula	network	transfer function (V_i/V_o)
Inductance L		$I=\frac{I}{L}\int_o^t Vdt$ or $I=\frac{V}{pL}$		$-\frac{1}{pR_xC_x}=-\frac{1}{pL}$ ($V_i\equiv V; V_o\equiv I$)
Capacitance C		$V=\frac{I}{C}\int_o^t Idt$ or $V=\frac{I}{pC}$		$-\frac{1}{pR_xC_x}=-\frac{1}{pC}$ ($V_i\equiv I; V_o\equiv V$)
Spring constant k		$F=k\int_o^t Udt$ or $F=\frac{kU}{p}$		$-\frac{1}{pR_xC_x}=-\frac{k}{p}$ ($V_i\equiv U; V_o\equiv F$)
Mass M		$U=\frac{I}{M}\int_o^t Fdt$ or $U=\frac{F}{pM}$		$-\frac{1}{pR_xC_x}=-\frac{1}{pM}$ ($V_i\equiv F; V_o\equiv U$)
Resistance R		$V=RI$ or $I=\frac{V}{R}$		$k=R$ ($+V_i\equiv I; V_o\equiv V$) $k=\frac{1}{R}$ ($+V_i\equiv V; V_o\equiv I$)
Viscous friction (coefficient = f)		$F=fU$ or $U=\frac{F}{f}$	or 	$k=f$ ($+V_i\equiv U; V_o\equiv F$) $k=\frac{1}{f}$ ($+V_i\equiv F; V_o\equiv U$)

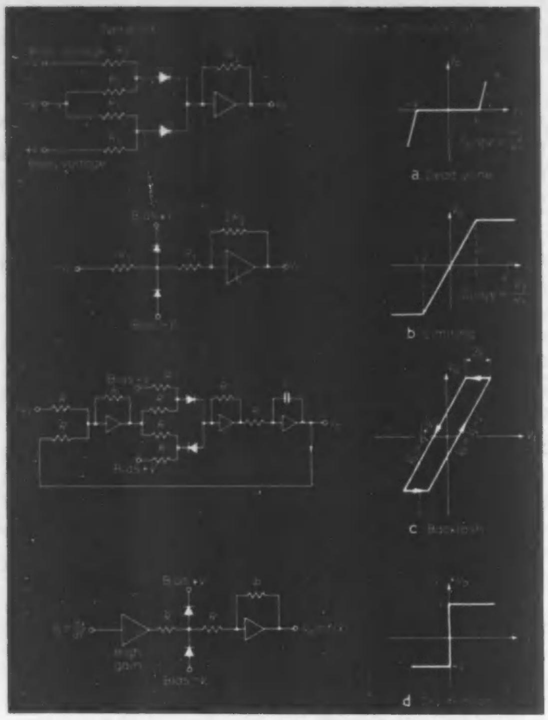


Fig. 11 A more realistic model of the simple feedback control system would include non-linear effects, some of which are shown in the drawing

kinematic or axis resolution solutions. The high-speed digital differential analyser will replace the analogue computer in these cases. An alternative approach is the use of the analogue computer to simulate the complete problem, with those sections of the problem requiring high computational accuracy duplicated on a high speed digital computer. The solution given by the latter is used periodically during the computation, to monitor and correct the analogue solution. In this way very high speed and accuracy may be obtained.

A serious limitation of present analogue techniques is the difficulty in generating functions of two or more variables. Although these may be generated more easily in the digital differential analyser or digital computer, there are many applications where computational speed is more important than accuracy, e.g. nuclear reactor studies, thermodynamic and combustion problems, etc. For such applications an attractive technique is a hybrid system, in which some mathematical operations are performed digitally, some operations in an analogue fashion and where the analogue mode of operation is preserved.

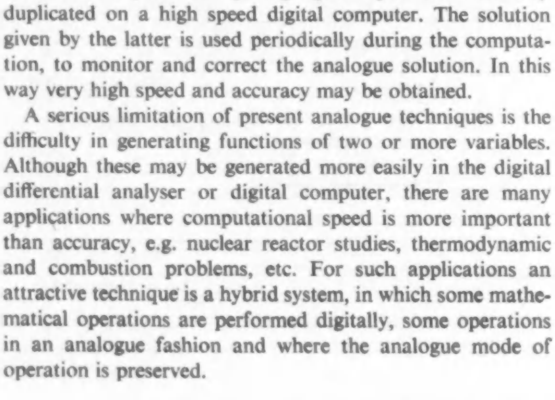


Fig. 12 The simulation of the dynamic performance of this nuclear power plant would involve many non-linear effects

Other desirable features which are becoming available or may be expected in the near future are:

Automatic setting of coefficients from punched paper tape.

Automatic programming of the analogue computer from punched paper tape.

More reliable, versatile and faster methods of analogue-digital and digital-analogue conversion for interconnexion between digital and analogue computers may also be expected.

APPENDIX

Referring to Fig. 5, we have

$$R = K_1\theta_i \quad \ldots (1)$$

$$B = K_1\theta_o \quad \ldots (2)$$

$$E' = R - B = K_1(\theta - \theta_o) \quad \ldots (3)$$

$$E = K_1(\theta_i - \theta_o) - K_5 p\theta_m \quad \ldots (4)$$

$$V_f = K_2E = K_2\left[K_1(\theta_i - \theta_o) - K_5 p\theta_m\right] \quad \ldots (5)$$

$$I_f = \frac{K_3V_f}{1 + pT_f} \text{ where } T_f = \text{ time constant of field circuit } = \frac{L_f}{R_f}$$

$$= \frac{K_2K_3}{1 + pT_f}\left[K_1(\theta_i - \theta_o) - K_5 p\theta_m\right] \quad \ldots (6)$$

$F(p) = K_4I_f$ where $F(p)$ is motor torque per unit field current . . . (7)

$$\text{i.e. } F(p) = \frac{K_2K_3K_4}{(1 + pT_f)}\left[K_1(\theta_i - \theta_o) - K_5 p\theta_m\right] \quad \ldots (8)$$

$$F(p) = Jp^2\theta_m + fp\theta_m = fp\theta_m(1 + \frac{J}{f}p) \quad \ldots (9)$$

(J = polar moment of inertia of motor and load; f is viscous friction coefficient)

Hence
$$p\theta_m = \frac{K_2K_3K_4\left[K_1(\theta_i - \theta_o) - K_5 p\theta_m\right]}{f(1 + pT_m)(1 + pT_f)} \quad \ldots (10)$$

$$p\theta_o = \frac{1}{n}p\theta_m \quad (\text{Note } T_m = \frac{J}{f}) \quad \ldots (11)$$

$$p\theta_o = \frac{K_2K_3K_4\left[K_1(\theta_i - \theta_o) - K_5 p\theta_o\right]}{nf(1 + pT_m)(1 + pT_f)} \quad \ldots (12)$$

$$\theta_o = \frac{K_2K_3K_4}{nf} \cdot \frac{\left[K_1(\theta_i - \theta_o) - K_5 p\theta_o\right]}{p(1 + pT_m)(1 + pT_f)} \quad \ldots (13)$$

$$\theta_o = G \cdot \frac{\left[(\theta_i - \theta_o) - \frac{K_5}{K_1}p\theta_o\right]}{p(1 + pT_m)(1 + pT_f)} \quad \ldots (14)$$

$$\text{where } G = \frac{K_1K_2K_3K_4}{nf} \quad \ldots (15)$$

or
$$\theta_o = G \cdot \frac{(\theta_i - \theta_o) - K_6 p\theta_o}{p(1 + pT_m)(1 + pT_f)} \text{ where } K_6 = \frac{K_5}{K_1} \quad \ldots (16)$$

Thus
$$\left[T_fT_m p^3 + p^2(T_m + T_f) + p(1 + K_6G) + G\right]\theta_o = G\theta_i \quad \ldots (17)$$

References

1. Truxal, J. C.: 'Control System Synthesis' (McGraw-Hill, 1955)
2. Leger, R. M. and Greenstein, J. L.: 'Simulate Digitally or by Analogue-Digital Combination' *Control Engineering*, Sept. 1956, pp 145–52
3. Booth, A. D. and Booth, K. H. V.: 'Automatic Digital Calculators' (Butterworth, 1953)
4. Convention on Digital Computer Techniques. *Inst. Elect. Engrs*, 1956, **103**, 13
5. Sprague, R. E.: 'Fundamental Concepts of the Digital Differential Analyser' *Mathematical Tables and Aids to Computation*, 1952, **6**, 37, pp 41–9
6. Palevskey, M.: 'The Design of the Bendix Digital Differential Analyser' *Proc. Inst. Elect. Engrs*, 1953, **41**, 10, p 1352
7. Braun, E. L.: 'Design Features of Current Digital Differential Analysers' *Convention Record of Inst. Elect. Engrs*, (part 4), 1954, Electronic Computers
8. Korn, G. M. and Korn, T. M.: 'Electronic Analogue Computers' (McGraw-Hill, 1952)
9. *Proc. Inst. Elect. Engrs*, 1953, Computer issue **41**, 10
10. Paul, R. J. A. and Thomas, E. L.: 'The Design and Applications of a General Purpose Analogue Computer' *Journal Brit. I.R.E.* 1957, **17**, 1
11. 'Control Survey—5. Analogue and digital computers' *Control*, Nov. 1958
12. Larrowe, V. L.: 'Direct Simulation by-passes Mathematics: Simplifies Analysis' *Control Engineering*, 1954, **1**, pp 25–31
13. MacLusky, G. J. R.: 'An Analogue Computer Simulating the Kinetics of a complete Nuclear Power Station' Journees Internationales de Calcul Analogique. (International Analogy Computation Meeting, Brussels, 1955, pp 170–4)
14. Wilson, I.: 'The Application of Analogue Computer Techniques to the Solution of Overall Nuclear Reactor Control and Safety Problems', pp 191–7
15. Leilby, D. W.: 'Analogue Computer Study of the Transient Performance of a Dual Cycle Water Reactor Nuclear Power Plant' *Trans. A.I.E.E*, 1958, **77**, pp 17–25

HOW TO APPLY PRESSURE CHARACTERISTICS OF LINEAR VALVES—3

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PRESSURE TRAVERSE TESTS FOR VALVES

A *pressure traverse test* gives a simple and sensitive indication of imperfections in a valve. The valve output ports are blanked off as described in Data Sheet 5 (November) and tapped with pressure gauges, indicating P or P_m (for P_m a differential gauge). The valve input is slowly varied through the full range and the variation in the stalled output pressure at the ports recorded against the input movement.

Assessing lap

The form of the pressure traverse should, with reservations, be similar to that of the $q_m = 0$ curves, shown in Data Sheets 4 and 5, and in this Data Sheet overleaf ($\bar{q}_m$). In a plot of P or $(P_1 - P_4)$ against X, the maximum slope will occur near the centre of the traverse and will be greatest when the valve is zero-lapped. It was shown in Data Sheet 5 that in an under-lapped valve, provided $-U \leqslant X \leqslant +U$, the slope of the q_m curve as it crosses the δ axis is, ideally, two. Referred to an axis of γ, this becomes $2X_{max}/U$ or $2/n$ (see equation 1 below). This value is greatest when $U = 0$: theoretically infinite, and in practice sometimes so great as to be difficult to measure. If the valve is over-lapped the slope in the centre of the traverse again falls off. The flow through the valve ports is usually turbulent up to and sometimes into the over-lap range, but in the simplest case, of laminar flow throughout the over-lap, the slope $dp/d\gamma$ in the centre of the plot would be X_{max}/L, where L is the over-lap at each port when the valve spool is centred.

A traverse of 90% supply pressure can be achieved by a good zero-lapped valve within a valve traverse of 1–2% of full stroke ($2X_{max}$). (A glance at the graphs will show that there is little point in using 100% supply pressure as the criterion.) In a relatively poor valve, including unintentional over- or under-lap, this figure may be as much as 5% or more. The servo reset error (see Data Sheet 5) can thus be up to five times greater. That this matters can be seen from an example.

Example

Consider a servovalve and rotary actuator operating at $P_s = 1000$ lb/in^2, with a maximum angular rate of 800°/sec. If the actuator has pistons with neoprene O-seals it will exhibit, typically, Coulomb friction requiring a value of P_m of, say, 90 lb/in^2, to initiate and maintain motion. The poorer valve must be deflected 0·5% of X_{max} to give a stalled output at this level and so initiate rotation. The actuator velocity will thereafter be approximately proportional to $(X - 0{\cdot}005\ X_{max})$ unless the velocities or loads become fairly large. This is borne out both by examination of the (p, q, γ)-graphs and in practice. Thus the system behaves as though the valve were over-lapped, regardless of its actual state. In a simple remote position control loop, this undesirable error would be as great as the steady-state velocity error at 4°/sec, and might well be significant if the velocity constant were low.

To be concluded

THEORY OF THE OPEN-CENTRE OR PARTIALLY UNDER-LAPPED VALVE

The definitions of Data Sheets 4 and 5 are now extended as follows (all quantities are vectorial unless specifically qualified):

p = The non-dimensional output pressure of the valve.

For 3-way valves $p = (2P - P_s)/P_s$ *For 4-way valves* $p = (P_1 - P_4)/P_s$

X = Valve spool deflexion.

h = Length of any *open* valve port: h is vectorial and is always positive for certain ports, always negative for the others; $+h$ and $+X$ are assumed similar in sense as well as direction.

U = Length of all valve ports when $X = 0$: U is scalar.

$\beta = h/h_{max}$ $\gamma = X/X_{max}$

$\delta = X/U$ $n = U/X_{max}$ (n is scalar)

Q_m = The incompressible flow rate into the oil motor.

$\bar{Q}$ = The (positive) no-load flow of an under-lapped valve for a spool deflexion $+U$.

$$\bar{Q} = C_q w\, 2U \sqrt{(P_s/\varrho)}$$

Q_{max} = The no-load flow when $h = +X_{max}$

Thus $Q_{max} = C_q w X_{max} \sqrt{(P_s/\varrho)}$

where C_q = Discharge coefficient
w = Width of the valve ports
ϱ = Oil density

$q_m = Q_m/Q_{max}$ $\bar{q}_m = Q_m/\bar{Q}$

From the above it follows that

$$\gamma = n\delta \quad \ldots (1)$$

$$q_m = 2n\bar{q}_m \quad \ldots (2)$$

Finally, the basic flow equation for linear valves is

$$Q = C_q wh \sqrt{(2\Delta P/\varrho)} \quad \ldots (3)$$

where ΔP is the pressure drop through the port.

The term 'linear valve' arises from the relation:

Port area = wh

and is justified under no-load conditions.

Outside the under-lap range

Data Sheet 4 shows that in the zero-lapped valve

$$q_m = \gamma\sqrt{(1 \pm p)} \text{ for} \begin{cases} X < 0 \\ X > 0 \end{cases} \quad \ldots (4)$$

It can easily be seen from the diagrams and definitions that the more general relation is

$$\frac{Q_m}{C_q w h_{max} \sqrt{(P_s/\varrho)}} = \beta\sqrt{(1 \pm p)} \text{ for } \begin{cases} h \leqslant 0 \\ h \geqslant 0 \end{cases} \quad \ldots (5)$$

It applies to valves of the type shown in the diagram whenever the spool deflexion X causes all the ports *aiding* any particular direction of flow to be open, and the remainder to be over-lapping. Thus, in the partially under-lapped valve, equation 5 applies outside the under-lapped range.

However, it is more convenient to 'non-dimensionalize' by relating all quantities to X_{max} rather than to h_{max}. Equation 5 is therefore converted:

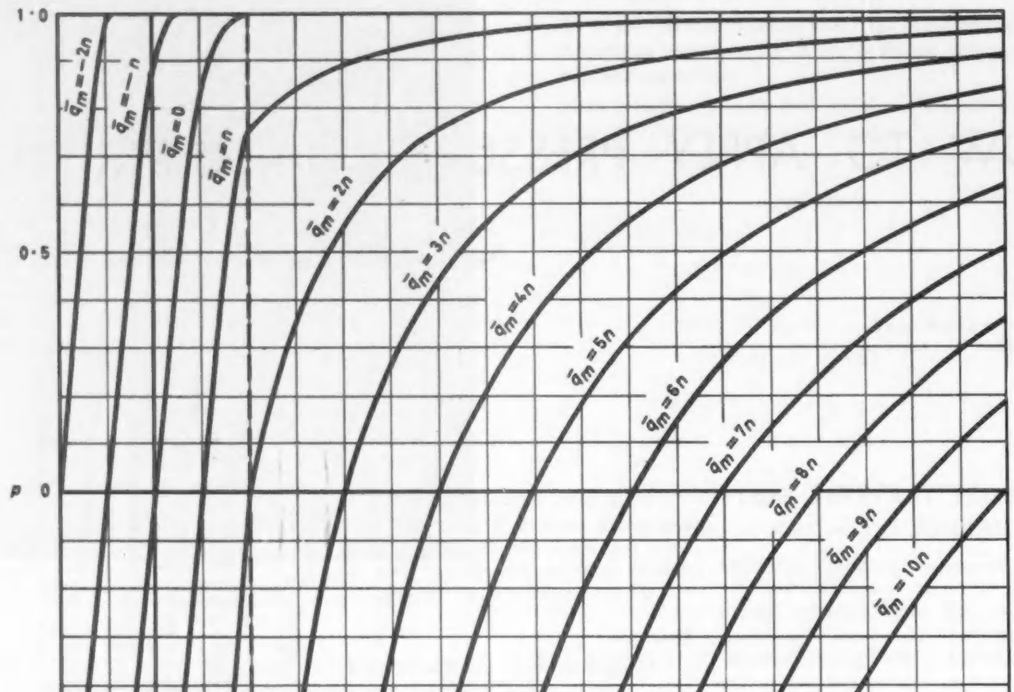
Since $h = \pm U + X$ for $\begin{cases} h \leqslant 0, X \leqslant +U \\ h \geqslant 0, X \geqslant -U \end{cases}$

(N.B. U is scalar, h and X are vectorial)

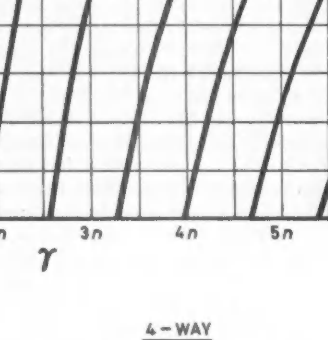
and $h_{max} = U + X_{max}$ (all positive values)

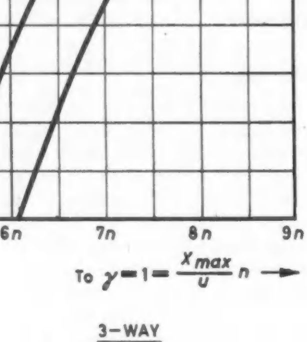
and $\beta = \dfrac{h}{h_{max}} = \dfrac{X \pm U}{U + X_{max}}$ for $\begin{cases} h \leqslant 0, X \leqslant +U \\ h \geqslant 0, X \geqslant -U \end{cases}$

DATA SHEET—6



Pressure output curves for a partially under-lapped valve. For negative value of γ rotate curves through 180° about the origin. The curves cannot be plotted to $\gamma = 1$ without sacrifice of generality





Multiplying equation 5 throughout by h_{max}/X_{max} gives

$$\frac{Q_m}{Q_{max}} = \frac{h_{max}}{X_{max}} \cdot \frac{X \pm U}{U + X_{max}} \sqrt{(1 \pm p)} \quad \text{for} \begin{cases} h \leqslant 0, X \leqslant +U \\ h \geqslant 0, X \geqslant -U \end{cases}$$

Thus $$q_m = (\gamma \pm n)\sqrt{(1 \pm p)} \text{ for} \begin{cases} X \leqslant -U \\ X \geqslant +U \end{cases} \quad \ldots (6)$$

Note that the maximum no-load flow is $(n + 1)Q_{max}$.

Within the under-lap range

Data Sheet 5 shows that in fully under-lapped 3- and 4-way linear valves

$$\bar{q}_m = [\tfrac{1}{2}(1 + \delta)\sqrt{(1 - p)} - (1 - \delta)\sqrt{(1 + p)}] \quad \ldots (7)$$

Equation 7 is applicable for $-U \leqslant X \leqslant +U$.

From equations 1, 2 and 7,

$$q_m = n\left[\left(1 + \frac{\gamma}{n}\right)\sqrt{(1 - p)} - \left(1 - \frac{\gamma}{n}\right)\sqrt{(1 + p)}\right] \quad \text{for } -U \leqslant X \leqslant +U$$

$$= (\gamma + n)\sqrt{(1 - p)} + (\gamma - n)\sqrt{(1 + p)} \quad \text{for } -U \leqslant X \leqslant +U$$

Summary

For the under-lap range $-U \leqslant X \leqslant +U$	$q_m = (\gamma + n)\sqrt{(1 - p)} + (\gamma - n)\sqrt{(1 + p)}$
For the range $X \leqslant -U$	$q_m = (\gamma - n)\sqrt{(1 + p)}$
For the range $X \geqslant +U$	$q_m = (\gamma + n)\sqrt{(1 - p)}$

As the first of these three expressions is not readily expressed in the form $p = f(q, \gamma)$, all are left with q_m on the left-hand side.

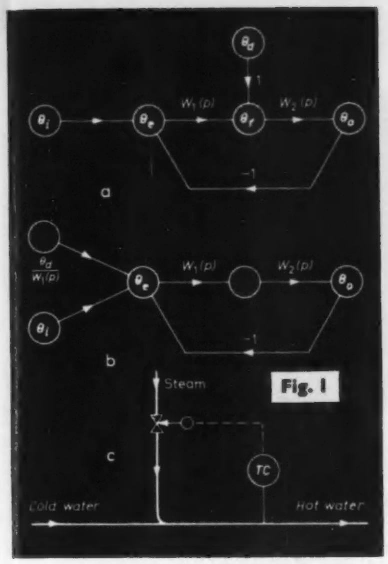


Fig. 1

PART 6

What is control engineering?

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PART 5 OF THIS SERIES (NOVEMBER) WAS DEVOTED MAINLY to the development of Nyquist's stability criterion, which, in its restricted but commonly used form, states: *A system will be stable on closed loop if, and only if, the plot of the open-loop transfer function $W_0(j\omega)$, for frequencies from $-\infty$ to $+\infty$, does not encircle the point* $(-1, 0)$.

Conditions of true instability, limiting stability and true stability were illustrated, and we pointed out that as the part of the open-loop plot in the region where $|W_0(j\omega)| = 1$ is shifted further from the point $(-1, 0)$, for a stable system, so the damping of the transient terms (in other words the relative stability) is increased.

System performance

In Part 4 (October) we showed how the step response could be found by frequency response and Fourier analysis techniques, approximating the step by a square wave or repetitive step. We also pointed out that the rounding of the square-wave response was due to the low-pass nature of the closed-loop sinusoidal response plot, i.e. the attenuation of the high-frequency components present in the input square wave. An oscillatory square wave or step response corresponds to a closed-loop sinusoidal response having a peak and thus accentuating a relatively small band of input frequency components. Frequencies above this band are attenuated as before. Thus the transient response of the position control system, and indeed of most systems, is determined largely by the plot of $W_0(j\omega)$ in the region where $|W_0(j\omega)| = 1$ and by its behaviour at higher frequencies.

When $W_0(j\omega) \gg 1$ over the range of input frequencies, then

$$W_c(j\omega) = \frac{W_0(j\omega)}{1 + W_0(j\omega)} \simeq 1$$

and the frequency spectrum of the output differs little from that of the input.

Where the system is required to follow a slowly varying input with great accuracy, therefore, we may conclude that special consideration must be given to the region where $W_0(j\omega) \gg 1$. In slowly and smoothly varying inputs the major features of the step response, i.e. rise time and overshoot, are of relatively little importance.

Thus we have selected two special inputs, the smooth slowly varying and the rapidly varying and identified the parts of the closed-loop frequency response, which are most important for these two inputs, as being the low-frequency and high-frequency parts respectively.

It is apparent that although, as we shall see, fairly simple solutions may be found for the two extreme cases, difficulty (in the form of complexity of calculation) does arise where the frequency spectrum is intermediate between the two cases. Thus, for high accuracy of following, this condition must be avoided (i.e. the system must have adequate bandwidth).

Disturbances

It is also relevant to consider the response of the system to any disturbances (such as wind loads on a radar dish) which may arise. Disturbances are extremely important in regulators, where the input (often called the set point) is fixed and the purpose of the control system is to minimize the effect of the disturbance on the system. The dependence diagram for a system of this kind is shown in Fig. 1a.

It is apparent that the response to θ_i is given by the closed-loop transfer function

$$W_c(p) = \frac{W_1(p)W_2(p)}{1 + W_1(p)W_2(p)}$$

whilst the response to the disturbance is given by

$$W_d(p) = \frac{W_2(p)}{1 + W_1(p)W_2(p)}$$

Hence

$$\frac{W_d(p)}{W_c(p)} = \frac{1}{W_1(p)}$$

and provided $W_1(p)$ can be made sufficiently large, the disturbance θ_d can be made to have negligible effect compared with θ_i. It is apparent that, if stability considerations are ignored, a large $W_1(p)$ also gives improved $W_c(p)$.

An alternative approach is to express θ_d as an equivalent input at the same terminals as θ_i, as shown in Fig. 1b, when it becomes clear that the problem is to choose $W_1(p)$ so as to produce the best rejection of the frequency

spectrum representing $\theta_d/W_1(p)$, whilst reproducing the frequency spectrum of θ_i as accurately as possible.

An example in which the disturbance and desired inputs appear directly at the same terminals is a radar set tracking a distant target; the disturbance is mostly random noise caused by a number of effects and may have a relatively large amplitude due to the distance of the target. An example involving the position control system already described would be variation of load torque on the output shaft. Many examples occur in process control, one being the steam water heater shown diagrammatically in Fig. 1c. The various inputs may be listed as due to change in water demand; change in input water temperature; and change of steam pressure and/or calorific value.

Stabilization

In designing a system we shall usually find ourselves with certain fixed parts, which may be represented by the transfer function $W_2(p)$ of Fig. 1a. Once the fixed parts are settled, we may modify the system in principle by inserting extra components as indicated in Figs. 2a, 2b and 2c. Any or all of these methods may be used in realizing a final design. Fig. 2d shows an arrangement using all the methods. The closed-loop transfer functions corresponding to the arrangements of Figs. 2a, 2b and 2c are

$$\frac{W_1(p)W_2(p)}{1 + W_1(p)W_2(p)}, \quad \frac{W_2(p)}{1 + W_2(p) + W_2(p)W_3(p)}, \text{ and}$$

$$\frac{W_2(p)}{1 + W_2(p)}[1 + W_4(p)]$$

We note that the second expression may be simplified if we take its reciprocal $1/W_c(p) = 1 + 1/W_2(p) + W_3(p)$. Thus the reciprocal of the closed-loop transfer function is the sum of: the reciprocal of the open-loop transfer function, the feedback compensation transfer function, and unity. Even when no feedback compensation is used, i.e. when $W_3(p) = 0$, the reciprocal of the closed-loop

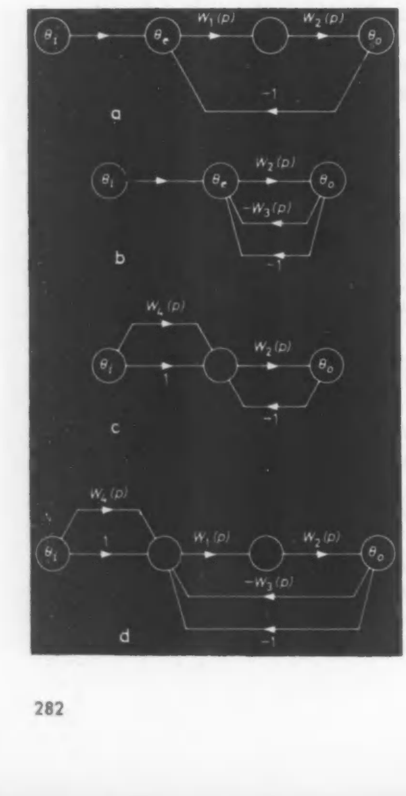


Fig. 2 Methods of compensating open loops

a Cascade

b Feedback

c Feed-forward

d General

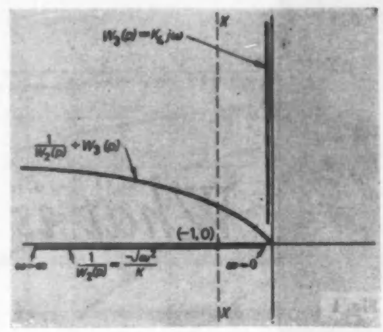


Fig. 3 Inverse diagram for feedback compensation

function is obtained from the open-loop reciprocal simply by adding unity. This should be compared with the direct closed-loop function

$$W_c(p) = \frac{W_2(p)}{1 + W_2(p)}$$

which involves vector division in order to obtain the closed-loop response from the open-loop response, as indicated in Part 5.

The inverse Nyquist locus

Thus when frequency diagrams on an arithmetic scale are used, and particularly where feedback compensation is used, substantial advantages in simplicity accrue from plotting $1/W_1(p)$ rather than $W_1(p)$. This type of diagram is known as the *inverse Nyquist diagram*.

By a method similar to that developed for the Nyquist diagram (see Part 5) we can show that a system is stable if its inverse Nyquist diagram does not enclose the $(-1, 0)$ point, provided that the open-loop transfer function has no zeros which lie in the right-hand half of the p plane. A proof of this statement is not given, but the reader is recommended to verify it for a number of simple transfer functions, taking care to investigate the behaviour of the inverse diagram at $\omega = \infty$.

The stabilization of the position control system by velocity feedback (see Part 3, September) will serve to illustrate the use of the inverse diagram. We assume for purposes of illustration that the viscous damping is zero. Then the system will be as in Fig. 2b with

$$W_2(p) = \frac{v_o}{v_e}(p) = \frac{K}{Jp^2}$$

and for velocity feedback

$$W_3(p) = K_4 p$$

The inverse diagram for $W_2(p)$, i.e. $1/W_2(j\omega) = J(j\omega)^2/K$ with $W_3(j\omega) = K_4 j\omega$ also plotted, is shown in Fig. 3.

The sum of the inverse-forward and the feedback compensation is also plotted (for a particular value of K_4). The reciprocal of the closed-loop transfer function is obtained simply by shifting the imaginary axis one unit to the left. It will be noted that the system has been stabilized by the addition of velocity (first derivative of output) feedback. In this simple case this is easily confirmed algebraically.

Thus

$$\frac{\theta_i}{\theta_o}(p) = \frac{1}{W_c(p)} = \frac{J}{K}p^2 + K_4 p + 1$$

$$= \frac{1}{K}(Jp^2 + KK_4 p + K)$$

Hence the characteristic equation is

$$Jp^2 + KK_4 p + K = 0$$

and the poles are

$$s_1, s_2 = -\frac{KK_4}{2J} \pm \sqrt{\left(\frac{K^2K_4^2}{4J^2} - \frac{K}{J}\right)}$$

Critical damping occurs when

$$\frac{K^2K_4^2}{4J^2} = \frac{K}{J} \text{ or } \frac{KK_4^2}{J} = 4$$

Thus

$$K_4 = 2\sqrt{\left(\frac{J}{K}\right)}$$

We note in passing that this arrangement is stable but does not involve the waste of motor torque in viscous damping, although viscous damping has a similar stabilizing effect. Several split-field motors are, in fact, made with built-in tachogenerators for this very purpose. (See *Control Survey*, September 1958, pp 118–9).

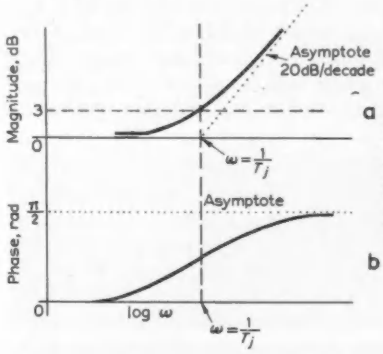


Fig. 4 Log plots of magnitude and phase for $(1 + j\omega T_j)$

By 'asymptote 20dB/decade' is meant a straight line whose y ordinate increases by 20 dB for a tenfold increase in ω, i.e. an increase of 1 in $\log_{10}\omega$

Log plots

Where cascade compensation (Fig. 2a) is used, it is apparent that multiplication cannot be avoided and it is often the case that a transfer function is the product of four or more separate factors. Since multiplication of several factors is involved, we might expect that a logarithmic method would be useful. Log plots are, in fact, particularly useful for the commonly occurring '*minimum phase*'* open-loop transfer function, because the transfer function can always be written in the form

$$\frac{K}{p^l} \cdot \frac{\prod_{j=1}^{m} (1 + p/s_j)}{\prod_{k=1}^{n-l} (1 + p/s_k)}$$

or

$$\frac{K}{p^l} \cdot \frac{\prod_{j=1}^{m} (1 + pT_j)}{\prod_{k=1}^{n-l} (1 + pT_k)}$$

When, as in a frequency plot, $p = j\omega$, this becomes

$$\frac{K}{(j\omega)^l} \cdot \frac{\prod_{j=1}^{m} (1 + j\omega T_j)}{\prod_{k=1}^{n-l} (1 + j\omega T_k)}$$

Consider the factor $(1 + j\omega T_j)$. This may be rewritten as $Re^{j\theta}$ where $R = \sqrt{(1 + \omega^2T^2)}$ and $\theta = \text{arc tan } \omega T$.

* 'Minimum phase' means having neither poles nor zeros in the right-half plane.

Separate plots of $20 \log_{10} R$ decibels (abbreviated 'dB'),† and $1/j \log_e e^{j\theta} = \theta$ radians against $\log \omega$ for values of ω from 0 to ∞ are shown in Figs. 4a and 4b respectively. Note that for $\omega \gg 1/T_j$, we have $20 \log_{10} R \simeq 20 \log_{10} \omega T_j$, the sloping asymptote in Fig. 4a, and $\theta = \pi/2$ which is the dotted asymptote in Fig. 4b.

For $\omega \ll 1/T_j$ the asymptotes are zero in both Figs. 4a and 4b. In Fig. 4a the asymptotes meet at $\omega = 1/T_j$. No matter what the value of T_j (provided it is always real) the plot is the same shape. Thus a template may be made which can be used for any T_j.

For a real pole, i.e. $1/(1 + j\omega T_k)$, the plot is the mirror image of that for the zero $(1 + j\omega T_j)$ when $T_j = T_k$.

In an integration $1/j\omega$ the log plot is as in Fig. 5.

The log plots for a complete transfer function are obtained by simple addition of the component plots of poles, zeros, integrations and the gain constant K. It is common practice, as will be illustrated by an example, to omit the gain constant from the plot and insert it by shifting the 0 dB axis in appropriate fashion.

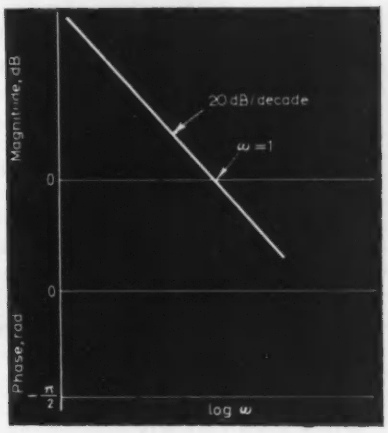


Fig. 5 Log plots of magnitude and phase for an integration $1/j\omega$

The remaining factors which may occur in a transfer function are complex conjugate poles or zeros.‡

A complex conjugate pole pair may be written in the form

$$\frac{1}{p^2T^2 + 2\zeta Tp + 1}$$

the conjugate complex poles being given by

$$s_1, s_2 = \frac{1}{T}[-\zeta \pm \sqrt{(\zeta^2 - 1)}]$$

Only values of $\zeta < 1$ need be considered since, for $\zeta \geqslant 1$, s_1 and s_2 are real and the plot for a real pole has already been described.

In a frequency plot with $p = j\omega$ the quadratic lag becomes

$$\frac{1}{1 + 2j\zeta\omega T - \omega^2T^2}$$

We note that for $\omega \gg 1/T$ the asymptotes are of magnitude 40 dB/decade and phase $-\pi$, and for $\omega \ll 1/T$ they are of zero magnitude and phase.

For $\omega = 1/T$ the asymptotes are of magnitude $20 \log_{10} (1/2\zeta)$ and phase $-\pi/2$.

† See appendix for explanation of the decibel.

‡ The pure time delay, although important and not difficult to deal with graphically, will not be dealt with here.

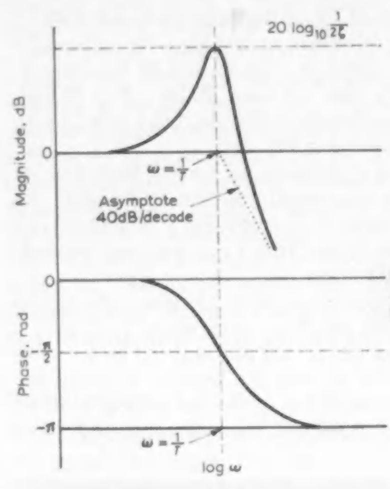


Fig. 6 Log plots of magnitude and phase for the complex quadratic lag

$$\frac{1}{p^2T^2 + 2\zeta pt + 1}$$

Hence the shape of the plot depends only on ζ and the position on the log ω axis depends only on T. A representative plot is shown in Fig. 6.

Use of phase-advance networks

As a simple example we take the stabilization of a position control system by addition of a 'phase advance' network as shown in Fig. 7a. The transfer function of the network of Fig. 7a, if a zero impedance source and an infinite impedance load are assumed, is given by

$$\frac{v_o}{v_i}(p) = \frac{1}{N} \cdot \frac{1 + pCR_1}{1 + pCR_1/N}$$

where $N = \dfrac{R_1 + R_2}{R_2}$

Evidently there is a zero at $p = -1/CR_1$, and a pole at $p = -N/CR_1$. A representative value of N is 10 and the log plots are then as shown in Fig. 7b.

The log plot for the position control with zero damping but with the realistic addition of a lag for the motor field inductance and amplifier output resistance is shown in Fig. 8a. We note that the phase lag as $\omega \to \infty$ is $3\pi/2$. For easy reference the direct Nyquist diagram is shown in Fig. 8b. Even at extremely low gain the system is only limitingly stable. When $|W_0(j\omega)| = 1$ the phase lag exceeds π by about 45° for the particular value of gain chosen in this example, and the system is well and truly unstable. Reference to the characteristics of the phase-advance network (Fig. 7b) shows that the maximum phase lead is only 55°, and so to obtain adequate stability with a single network of this type we must select CR_1 such that the maximum phase advance occurs at a frequency several times less than that for which $\omega = 1/T_f$, where T_f is the motor field time-constant. On these grounds we might select the CR_1 value to give maximum phase advance at $\omega = 1/10T_f$, when the phase lag due to T_f is approximately 5°.

Reduction of gain

The log and direct Nyquist plots for such a condition are shown in Figs. 8c and 8d. We now require to select a new gain constant for the position control. Evidently, in spite of the reduction of low-frequency gain by the phase-advance section, the gain is still much too high, and we shall obtain best relative stability by reducing the gain by a factor of about 30 dB so that the line KK becomes the new 0 dB axis (Fig. 8c). The new scale is indicated for Fig. 8d by the new $(-1, 0)$ point at about $(-30, 0)$ on the original scale. Fig. 8e shows the direct Nyquist diagram for the system, stabilized by the addition of phase advance and reduction of gain, to the same scale as the original diagram before stabilization.*

Phase margin and gain margin

Significantly, we have specified the stability in terms of one quantity only—the phase shift when $|W_0(j\omega)| = 1$, rather than specifying the complete locus for W_0 or W_c. The specification is adequate for this particular case, since a considerable increase in gain (> 20 dB) is necessary to produce complete instability and a considerable decrease is necessary to produce limiting stability. It is common practice to specify stability in terms of two quantities, namely, phase margin and gain margin. These are stated as (π − phase lag) in radians when $|W_0(j\omega)| = 1$ (indicated by ϕ_m on Fig. 8e), and gain increase to

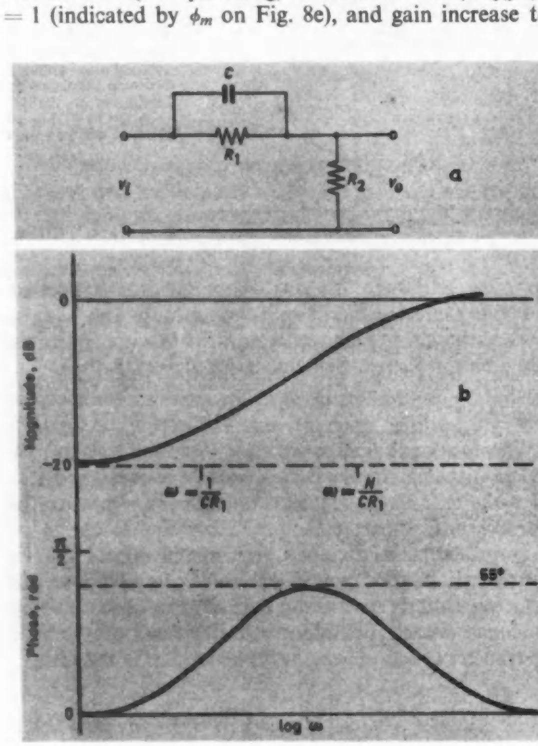


Fig. 7
a Phase-advance network
b Log plots for network of Fig. 7a with $(R_1 + R_2)/R_2 = 10$

give a phase lag of π, when $|W_0(j\omega)| = 1$ (indicated by K_m on Figs. 8c and 8e).

Now we chose CR_1 and the final gain constant in terms of $1/T_f$, and although this will give an adequate step response it has no obvious connexion with system errors in following a low-frequency signal. Indeed, for a sufficiently slowly varying signal it has no significance at all.

* If low-frequency errors were important this problem would more likely be tackled the other way about; namely, a certain gain would first have been chosen based upon tolerable low-frequency errors; a network would then have to be found which had sufficient phase advance to give adequate stability with that value of gain. The simple phase-advance network which has been chosen in this case would not normally give sufficient phase advance for a system of this type involving two integrations.

Summary

Methods of improving system performance (compensation) have been listed as

1. Cascade compensation
2. Feedback compensation
3. Feed-forward compensation.

Examples have been given of the use of the first and second of these methods foı improving system stability (*stabilization*), and serve to illustrate the relative usefulness of two different methods of plotting frequency-response data, namely, logarithmic plots and the inverse Nyquist locus.

The emphasis in this article has been on stabilization techniques which are most important for systems required to give good performance* in response to ıapidly varying inputs; in such systems, owing to physical limitations of bandwidth, the system performance is determined primarily by the high-frequency portion of the frequency response diagram. When the input is a relatively slowly varying smooth signal, then the performance is primarily determined by the low-frequency portion of the frequency response diagram, and the system transient response becomes of relatively little importance. If the signal is slowly varying but not smooth (e.g. contains steps of velocity) the system transient performance and steady-state performance are both important, and it is necessary to 'shape' both 'ends' of the frequency locus. A problem of this kind will be dealt with in the next article.

Appendix

The *decibel* is a unit that the control engineer has inherited from the communication engineer; it is defined for the purpose of these articles as follows:

$$\text{Gain in decibels} = 20 \log_{10} \frac{\text{Output quantity}}{\text{Input quantity}}$$

We call the decibel a unit of gain but it is not necessarily dimensionless; furthermore, according to our definition it has little or nothing to do with the power gain.

The communication engineer first used the decibel as a measure of power gain. It was therefore dimensionless and defined as

$$\text{Gain in decibels} = 10 \log_{10} \frac{\text{Power out}}{\text{Power in}}$$

However, in many applications to communication networks the input and terminating impedances of the system weıe purely resistive and equal, thus leading to the modified definition:

$$\text{Gain in decibels} = 10 \log_{10} \frac{V_2^2/R}{V_1^2/R} = 20 \log_{10} \frac{V_2}{V_1}$$

where V_1 is the input voltage V_2 is the output voltage, and R is the terminal resistance. The unit was then used by control engineers and corrupted as indicated above.

V_2/V_1	dB	V_2/V_1	dB
100	40	$\frac{1}{2}$	approx. − 6
10	20	$\frac{1}{10}$	− 20
2	approx. 6	$\frac{1}{100}$	− 40
1	0		

* Accuracy in following is perhaps the most important characteristic of system performance for most applications.

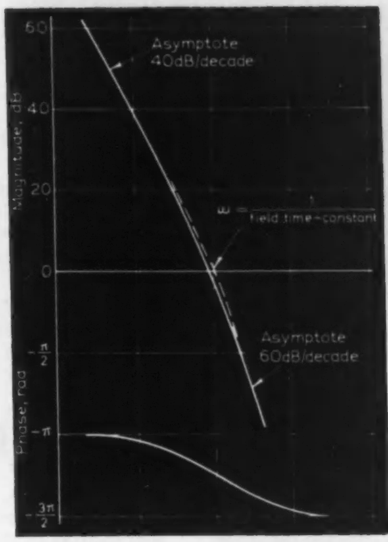
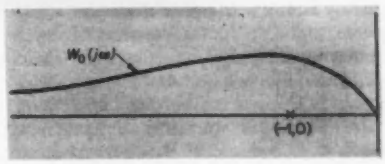
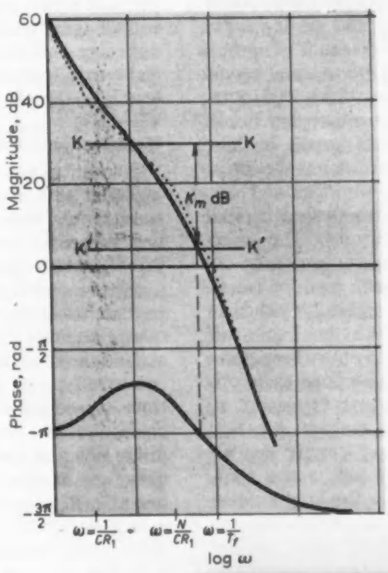


Fig. 8

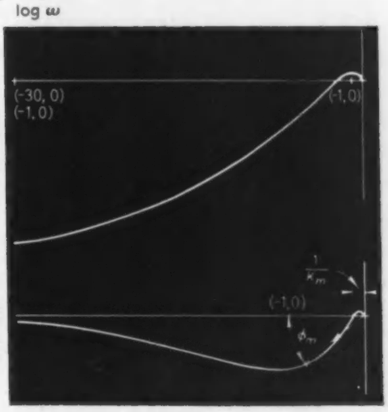
a Log plots for position control with zero damping but including field lag



b Direct Nyquist diagram corresponding to log plots of Fig. 8a

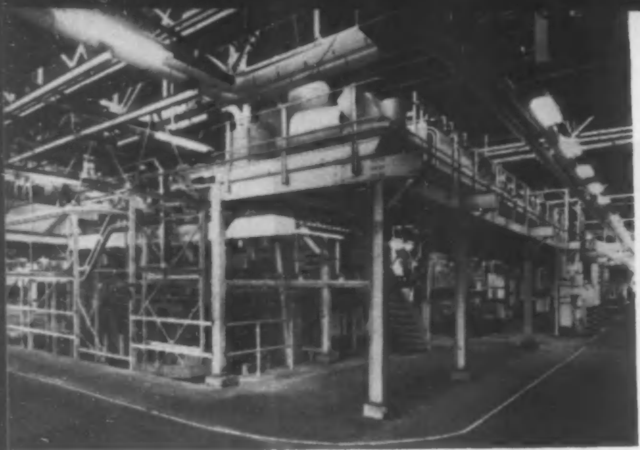


c Position control with phase advance log plots (the dotted line is a straight-line approximation to the curve)



d The position control system may be stabilized by a reduction of gain to 1/30 of its original value

e A statement of phase margin ϕ_m and gain margin K_m together indicate 'degree of stability'



CONTROL IN ACTION

1600 sq. ft. an hour and no manual control needed

Automatic plating at Vauxhall's

INSTALLED AS THE LAST MOVE IN A £36 million four year expansion programme, the Canning straight through automatic plating plants at Vauxhall Motor's Luton works are the largest of their type in Europe, and CONTROL was recently invited to see them in action. Their size is certainly impressive: each is 23 ft high, 60 ft wide and steel pressings move through over 200 ft of assorted cleaning and plating tanks at the rate of about 800 sq ft of surface an hour. The two plants are served by an auxiliary King Stan-Run overhead conveyor system carrying hooks suspended from 240 small trolleys, and from the point where the components are loaded onto jigs and suspended from these no further manual intervention is necessary. The overhead trolleys are continuously in motion, and automatic transfer mechanisms at the input and output ends of each plating plant pick the frames off the trolleys, feed them onto the plating conveyor system and unload them onto the auxiliary conveyor again at the other end. The first of the two plants applies a heavy copper deposit and this is polished before the components move back to the bright nickel and chrome plant from which they go directly to the assembly lines. Besides loading and unloading, automatic features include duplex main drives to reduce the drag load on the main conveyor, automatic lubrication for conveyor chains and contact track, provision for chemical make up remote from the process tanks and a general control from control rooms built on the upper platforms. Around each plant is erected a massive steelwork structure which supports the conveyor system, rectifiers, transformers, storage tanks and the platform and cat walks for the plant operators.

The conveyor system of the copper plant runs between two rows of 22 process tanks at 12½ in./min supporting a series of 138 flight bars which extend over the tops of the tanks on either side. They are spaced on the twin strand link conveyor and held in position by flared 'U' shaped plates attached to links. During plating the flight bars, supporting the jigs of components, are carried by the conveyor on hard drawn, high conductivity copper track above the tops of the process tanks from one end of the plant to the other. At the discharge end, the conveyor carries the flight bars upwards and back over the length of the plant to the loading end.

Magslips keep the drives in step

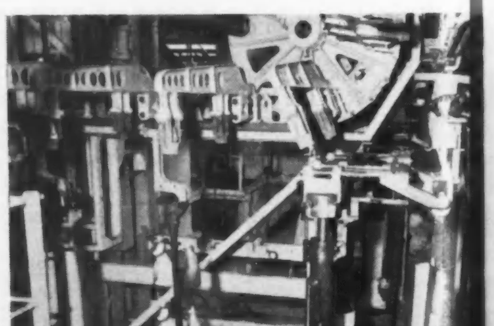
Two drives are fitted to the conveyor —one at each end—each using a fixed speed motor, Heenan-Dynamatic coupling and reduction gear. It is essential that the ends of the conveyor should be positively synchronized, irrespective of any slack in the conveyor chain, to ensure accurate transfer of components and to achieve this each coupling is controlled by an electronic unit giving close speed holding; the necessary correction in speed to keep the two drives positively in step is given by the out-of-phase signal from two Magslips, one at each end of the conveyor. This is a control of sequence. The main drives are protected by shear pins, which if broken will stop the whole plant and give appropriate light signals in the control room, indicating the precise location and cause of the stoppage. In the pits emergency stops are effected by means of a trip-wire system; all stops again are connected to the warning light system, together with over-run switches on the tower traverses. All emergency stop buttons are interlocked, and the plant cannot be started up until the same button is switched to the 'on' position.

The components are lifted out of one tank and lowered into the next by means of 23 towers spaced along the central conveyor. The towers are fitted with a carriage and when a flight bar approaches a transfer station a limit switch is operated which starts the elevator motor. The carriage is controlled and moves up the tower lifting the flight bar with it. At the end of the travel a limit switch operates and checks the movement. The next step is to slide the flight bar forward, and this is done by a separate system arranged so that the distance moved is sufficient to clear the lips of the abutting tanks and allow the jigs to be lowered cleanly into the next process tank. When the flight bar reaches this position, the lift motor reverses and the elevator is lowered, placing the bar back on the moving conveyor.

King conveyors feed Canning plant

The auxiliary conveyors serving the main conveyors are of a special cycle controlled type. They carry trolleys which are brought on loops into one of five bays, and here they are loaded with

A bumper for a Vauxhall 'Victor' is lifted with other components off the hooks suspended from the auxiliary conveyor on the right and placed on one of the flight bars of the plating machine conveyor by the automatic transfer mechanism in the centre



jigs that have been filled with the polished work. The trolleys are then moved through the loops onto the conveyor which transports them to a storage point before the loading unit. At the correct time a pulse is received from the plant control and four jigs are carried by the trolleys to the loading position. At the correct point they are automatically stopped and four pairs of arms from the transfer mechanism lift the jigs off the conveyor and place them on the flight bars of the plating conveyor. After the jigs are clear of the trolley a limit switch is actuated by the transfer arms and operates solenoid valves; when each trolley is released it resets its own stop mechanically. As each trolley approaches the stop in front of it it reopens it electrically, and a counting device is brought into operation to stop the fifth trolley. If the trolleys were not in place at the load points when a loading arm was in position ready for transfer the entire plant—both Canning plating installation and auxiliary conveyor system—would shut down. After unloading, trolleys by-pass the plating plant and move to the discharge end of the process line.

Loading, unloading is automatic

Meanwhile, four jigs of components have arrived at this end ; these are lifted off the flight bar by the unloading unit, rotated through 180 deg and placed onto the trolleys of the conveyor. At a signal, the trolleys move along the conveyor to the unloading bay. Each trolley selects its appropriate bay where the components are removed from the jig. The trolley and empty jig returns to the line and passes through to the loading bay.

The current available for the electrolytic processes totals 71 000 amps, which is transformed from the mains supply by banks of oil-immersed metal plate rectifiers, twenty in all; twelve of them are motorized, giving infinitely variable control. Current is fed to process tanks through aluminium bus bars, and current for the electrolytic operations is passed to components via the flight bars which in turn collect current from a copper track beside the main conveyor. The entire electrolytic installation is controlled at one point at the central control panel, and the conveyor pump and filtration equipment have separate control points on the same panel.

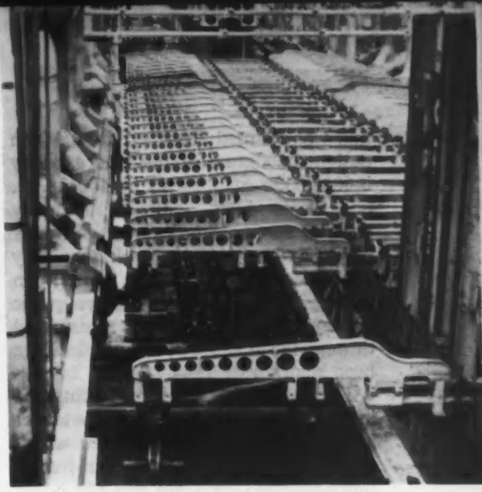
The nickel-chrome plant is designed on much the same lines as the heavy copper installation. It is slightly longer —262 ft against 217—and includes 32 tanks in each line.

Auto-controls relied on

Both plants have central control rooms which consist mostly of indicating lights. The plants more or less run themselves and in any case no provision is made for operating the plant manually if the control system breaks down. 'Naturally, we had a few troubles at first,' said Vauxhall's planning engineer. 'But we made a few minor alterations and it all goes pretty smoothly now.'

Switches fitted to the plant include pressure types to indicate when fitters are approaching the choking stage, and simple solution level switches which operate when the level in any tank falls too low. The chrome tanks are fitted with Cambridge flow indicators and thermostatic controls (in a chilled water tank). Refrigeration equipment controls the temperature rise and the chrome solution is heated and cooled by pumping it through an external heat exchanger. A motorized valve is connected to one side of the pump motor on this: should the pump fail, the process heat system will be automatically turned off by an alternative electrical circuit operating the motorized valves.

Warning of any irregularity in plant operation is given by the indicating lights in the control rooms. A klaxon



These flight bars carry the components through the plating tanks on each side of the central conveyor. The bar in the foreground is approaching the end of a tank and will automatically travel up the tower on the right and down again into the tank beyond

alarm was originally fitted, but is now little used. 'It made the devil of a row,' said the planning engineer. 'Some other modifications have been made,' he told CONTROL. The original control circuit, which was supplied by Teledictor, was infinitely variable, as each station was individually controlled by a motorized cam-operated counting unit. The purpose of these units was to open the solenoids controlling the trolley stops at the load and unload ends of the plant, four times. A further switch mounted over the trolley stops ensured that all stations were occupied when the load and unload arms on the Canning plating plant operated. In the light of experience, this system was modified and one counting unit was used to operate all the solenoids at each end of the plant. The initial signal which starts the counting unit is still received from a switch mounted on the Canning plant, but the three subsequent calls are made by a switch mounted on the King's conveyor, operated by trolleys passing through. The fourth trolley passing this latter switch returns the counting unit to its zero position.

CONTROL IN ACTION

Rolling by remote control

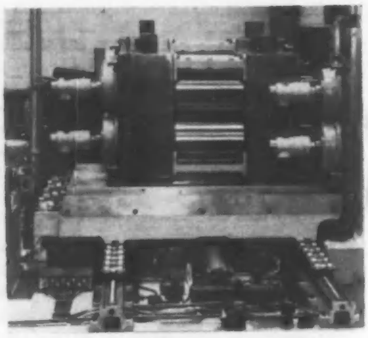
France gets British mill for active materials

A REVERSING COMBINATION MILL incorporating completely automatic roll changing and constructed so that it can be enclosed in a 'glove box' and operated from a small console outside has been made by a British firm for the French nuclear research centre at Saclay. It was developed for the Commissariat à l'Energie Atomique by Albert Mann's Engineering Co Ltd of Basildon, Essex, which has made several small mills for the British and French atomic authorities in the past—all designed to enable radioactive fuel element materials to be rolled inside protective perspex or steel glove boxes. While conventional practice could call, for instance, for a 2-high hot breakdown mill, a 2-high cold intermediate mill, a 4-high cold sheet finishing mill and possibly a form rolling mill, an obvious preference arises in this work to use a single machine capable of handling all rolling needs, since at these early stages the quantities involved in individual fuel element fabrication orders are likely to be small.

The new machine is much bigger than previous types—a 10 in. dia $\times$ 14 in. face width 2-high/4-high job fitted with four sets of rolls—and it was considered advisable to dispense with the usual manual methods for changing them because of their size and weight. The

mill was adapted from a Stanat/Mann design; maximum rolling load capacity is 600 000 lb at a speed of 100 f.p.m., and it is fitted with an infinitely variable speed 2 h.p. screwdown motor drive and a 100 h.p. electronically controlled Ward-Leonard type main mill drive. Screwdown pressure gauge and metering of the torque transmitted through the universal joint spindles have been incorporated.

Each set of rolls is self-contained in its own chocks and the sets not in use are held on a carriage which moves on rails alongside the frame. Individual roll units are slid across the carriage by a lead screw fitted with



Each set of rolls is self-contained in its own chocks and the sets not in use are held on this carriage, which moves on rails alongside the frame

Pollard thrust bearings and driven through a pinion by a hydraulic motor.

Rolls changed by pushbutton

A combined Timken mounted double helical reduction gear and pinion stand designed at Basildon transmits the torque to the universal joint spindles, the gearbox itself being driven by a Crompton Parkinson 26/100/100 h.p., ventilated and separately excited motor. Power is provided by a Ward Leonard set comprising a Crompton Parkinson 1450 rev/min, 0/420 volt, 191 amp shunt wound motor generator set mounted on a common bed plate. Ward-Leonard control is used because the company found it the most economical way of obtaining the drive motor speeds required, namely, 80–160 f.p.m. constant horse power range, and 5–80 f.p.m. constant torque range.

The rolls are adjusted by means of the 2 h.p. drive motor—mounted on top of the gearbox—through a double worm reduction to the screwdown spindles, and a Westool magnetic clutch enables individual adjustment of each side of the mill to be made. Screwdown speeds are variable from 0·18 mm a second for cold rolling up to 2·6 mm a second for hot rolling.

The roll changing mechanism is actuated from the control desk and the roll assembly required can be selected by a switch. Operation of the change button starts the programmed electro hydraulic sequence: (1) the screwdown is disconnected from the top roll (2) the screwdown rises to a position which will accept any roll configuration (3) the jibs which retain the chocks in position in the mill housings are withdrawn (4) the roll assembly is moved onto the roll carriage (5) while the roll carriage is withdrawn support is given to the universal spindles (6) the roll carriage is indexed to line up the new roll assembly selected (7) the universal spindles are adjusted to cater for the roll centres of the selected roll assembly (8) the new roll assembly enters the mill (9) the jibs lock the chocks and hold the roll assembly in position (10) the screwdown mechanism collects the new top roll assembly.

Photocells lock sequence

To ensure perfect engagement of the drive spindles the sequence is locked by a photoelectric device so that it can operate only when the squared driving ends on the universal shafts are aligned with the female drive sockets on the rolls. Inching control is provided to bring the shafts to the correct position. Components of the hydraulic system were supplied by Keelavite Hydraulics of Coventry, and the sequence is controlled by solenoid operated valves. Limit switches are used to signal the relays at the completion of one motion and trigger off the next.

Lefthand or righthand roll pressure or the sum of both can be read at the control desk; they are measured by Davy-United load cells located between the screwdown and the top roll chocks. The upper roll neck torque, lower roll neck torque and the sum of both can also be measured using strain gauges on the universal driving spindles, the signals being transmitted via slip rings and brushes mounted on the universal joints. A two-pen high-speed recorder is provided at the control desk for recording the roll pressure and roll neck torque.

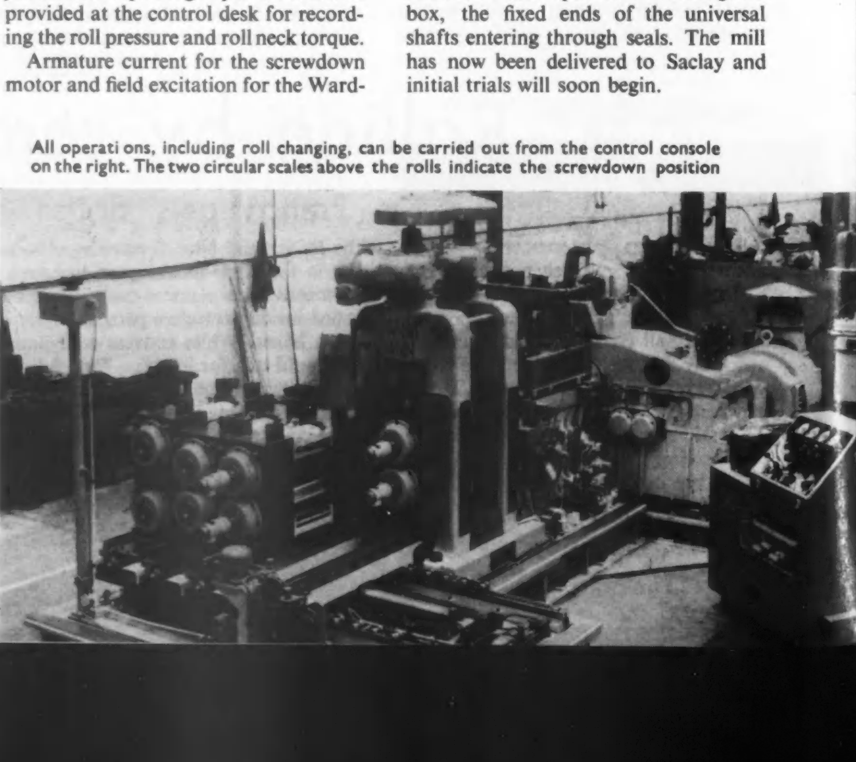
Armature current for the screwdown motor and field excitation for the Ward-Leonard set are supplied by a new system of pulse-controlled thyratrons developed by Albert Mann's electronic laboratory. It is reported to be extremely flexible and economical and the company has applied for a patent. The pulse control method is employed, say the company, because it is independent of anode wave form, does not drive the grid positive at any time and in consequence an extremely stiff control of the firing angle of the thyratron may be obtained without the use of feedback control. They claim that due to the extreme compactness of the electronic components a space saving of the order of 8 to 1 has been obtained for the equipment itself and for spares storage. In fact the small control console not only incorporates the 2 h.p. variable speed screwdown motor control, but all the relays associated with solenoid control of the hydraulic circuits, as well as the amplification and recording apparatus required for the torque and screwdown pressure system. It enables close automatic control of tension to be carried out and has made the introduction of programme control comparatively simple.

New thyratron technique

The same technique of pulse-controlled thyratrons is used in part of the roll change control circuit. The motive power of the servo which positions the upper roll universal joint when in the two-high position is hydraulic and control of the cylinder is obtained from a 4-way hydraulic valve operated by two d.c. solenoids in opposition. These are powered by two grid controlled rectifiers (thyratrons) which in their turn are controlled by the pulse technique.

D.c. motors are undesirable for operation in argon atmospheres as the gas is easily ionized, which causes electric breakdown. Thus the gearbox and motor are kept outside of the glove box, the fixed ends of the universal shafts entering through seals. The mill has now been delivered to Saclay and initial trials will soon begin.

All operati ons, including roll changing, can be carried out from the control console on the right. The two circular scales above the rolls indicate the screwdown position



TUBES AND TEXTILES - these are just two of the products now being manufactured with the aid of computers. Here are four applications described at the recent Symposium run in conjunction with the computer exhibition.

Putting computers to work

IRON ORE

Leo plans digging programme

At the Corby works of Stewarts & Lloyds the Leo II computer is now doing a job which was previously not regarded as a calculation task at all—rather one involving experience and the intelligent application of judgment. Corby blast furnaces are supplied almost exclusively from local ore and for several months now the computer has taken over the planning of the digging programme in the eleven pits. Giving details of the project, N. C. Pollock, of the company's organization and methods department, said the ore obtained is low grade and its chemical makeup varies considerably from pit to pit and from week to week. In allocating each day's digging programme there are three principal problems to overcome: (a) the quantity taken from each pit must be such that when used in the ore bedding plant it provides ore which both in amount and makeup is as close as possible to the furnace requirements, (b) each pit should work as far as possible at its most economic capacity, (c) since the diggers move along continuous strips, one day's finishing point is the next day's starting point; the quality of the ore to come is determined by laboratory analysis of samples and a day's programme must be arranged so that the next day's starting points allow an equally good mixture to be obtained from the eleven pits on that day.

Before the arrival of Leo the job was done by trial and error calculations on a basis of intelligent guesswork backed up by calculation at each stage, until the planner was satisfied he had obtained the best mixture he could get. The problem of leaving the diggers in a position to obtain an equally satisfactory mixture on the following day was dealt with in a fairly rough and ready manner by maintaining charts coloured to show the kind of ore available in each of the sections soon to be dug. A manual scrutiny of these guided the planner in selecting reasonable quotas.

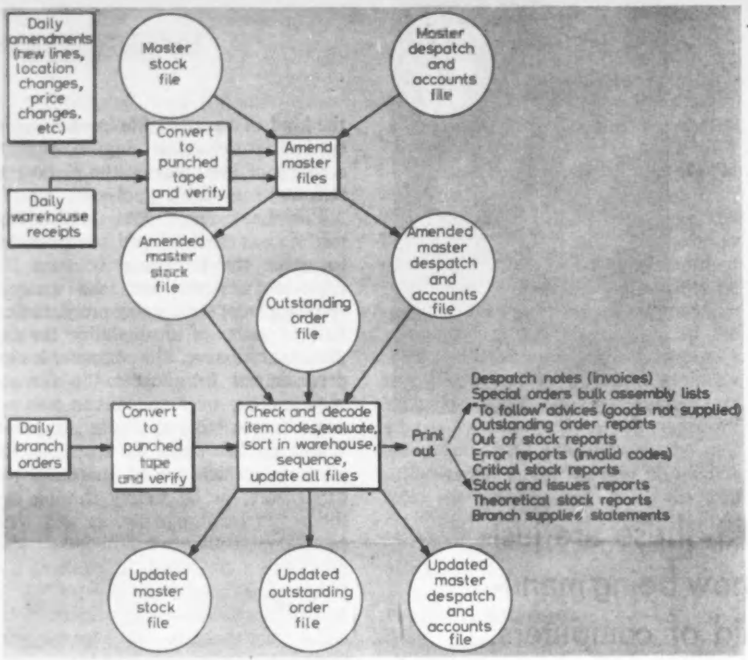
For Leo some more 'unthinking' method was required, and it was decided to make the difference between the required analysis and the analysis resulting from the digging programme a kind of 'index of unsuitability' for any particular mixture. The computer is now programmed to allocate the furnace requirements over the eleven pits on some simple basis as a starting point. It can do this either by repeating the allocation which proved successful the day before, or by simply sharing out the requirement equally. It will then calculate the mixture resulting from this distribution and the total value of the index of unsuitability, and go on to attempt to improve this allocation by exchanging wagons between the pits until all possible combinations have been tried. When a stage is finally reached where any further transfer between any two pits would cause the index to rise, then the best solution has been reached.

Leo programmes are run daily, and it maintains at any time not only an allocation of digging programmes for the following day, but a complete set of allocations to cover the whole of the next week's digging—normally five sets of allocations to cover five days. When going through its improvement routine, it bases the decision whether to accept or reject a transfer of wagons not merely on the effect that such a transfer has on that day's mixture, but, since it also recalculates the mixture which will result on the following four days, on these effects as well. It was hoped that this more precise form of planning digging programmes would both produce better mixtures (in that the computer would not allow the pits to get into a state from which adequate mixtures are not available), and produce a good deal of useful information to the management in that they would know, at least approximately, some days ahead what the demands on each pit in the short term were likely to be.

CHEMICALS

Emidec will keep stock

Details of the electronic data processing system which Boots Pure Drug Co plan to start next year with an Emidec 1100 computer (*News Round-up* October) were given by D. S. Greensmith. It will cover the processing of orders and stock inventories. When the branch orders are received in Nottingham, the envelopes will be sorted in departmental groups and passed to the data-processing centre where the order details will be



This sequence of operations covering the processing of orders and stock inventories will be carried out with Emidec in Boots' data processing centre

converted into punched paper tape; this will form the daily input for the computer.

It is proposed to keep on magnetic tape in the data-processing centre a perpetual inventory for each of the warehouses. When the orders are read into the computer, they will be checked against this master stock record. If a code has been inaccurately written, the computer will reject this order item and produce an error report. If an item ordered is out of stock, particulars will be recorded in a special 'to follow' file kept on magnetic tape. If the item is in stock, it will be priced and the amount expended. Subsequently, on a branch-by-branch basis, these items will be sorted into warehouse bin-number sequence. A proper alphabetical description of the goods will be attached and on its output-printers the computer will produce order/invoices giving details of the total value of goods involved. These will be in duplicate to enable one copy to be forwarded to the branch. They will bear details as to normal method of dispatch, and a serial number for each invoice will be calculated and printed on the invoice by the machine.

Production control next

On the accounting side, the computer will maintain a complete record of all supplies to every branch. The branch will receive with the goods a copy of the printed order/invoices produced by the computer. These will be priced and totalled so that the branch will know the value of the goods it has received. All goods to branches are invoiced at selling price: in consequence the figures now to be supplied, when read in conjunction with branch-takings figures, will enable branch managers to keep a close and continuous watch on the level of stocks.

The scheme is a data-processing task of considerable magnitude, Mr Greensmith said, and future plans for the computer include control of production.

TEXTILES

Deuce trebles production

By reorganizing its production control system and hiring time on a Deuce computer the Midlands textile manufacturing firm of Job White & Sons has almost trebled direct productivity in the sections concerned. This was disclosed in a paper by R. B. Baggett, joint managing director of the company, and G. H. Davis, of English Electric's computer division. The Deuce is hired for between one and two hours a week at a charge of about £50 and its output documents directly control most of the detailed manufacturing operations. Cost of writing the programme, which contains approximately 1200 instructions, worked out at about £3000.

The factory, employing about 600 people, buys yarn of various kinds, dyes it, knits it into fabrics and assembles the fabrics into articles of clothing. The complexity of the job arises from the large number of different articles, fabric patterns and yarns concerned, each in several different colour combinations, and the number of different types of knitting machine in use. Production is generally to customer orders, so that the production-control system has to accept orders and produce all the necessary documents to control, progress and co-ordinate production. Main objects of the system are to standardize procedures on the shop floor—thus increasing individual productivity—and to provide a centralized control which reduces the accumulation of stocks of yarn and fabric at various points in the production flow. At the centre of the system is the introduction of the measured winding method of knitting machine control, in which the precise yarn requirements for each knitting run are calculated and the yarn supplied to the knitter wound onto bobbins in exactly the lengths required. 'This involves considerable calculation and was the original reason for introducing a computer,' said the authors. Under the old system all bobbins were fully wound and each was changed when it ran out.

1000 winding instructions each week

The computer operation falls naturally into two phases. Input to the first consists of information from 'cutting cards'—giving details of each type of article ordered, fabric specification data—including production required for this fabric during the week, article specification data—including usage of the fabric concerned and economic production batch limits, and last making order number used. The output of the first phase is: (a) making orders—each making order covering one production batch, (b) winding instructions controlling the winding of yarn onto bobbins—one for each fabric colour within each production batch and designed to minimize the number of occasions during a run on which it is required to change bobbins, and (c) production summaries—summary of winding instructions for each knitting shop.

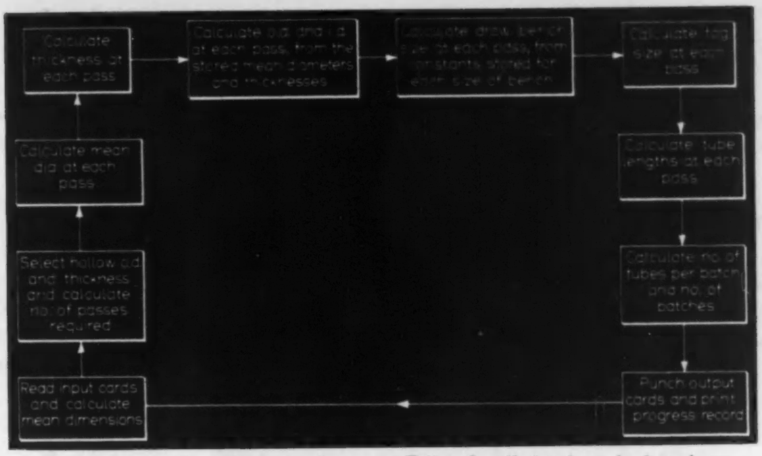
There are 200 to 300 different fabric designs, with about 200 new designs added each year; yarn types total 30 with 25 different colours for each type. Each week on average the computer issues 125 making orders and 1000 winding instructions—each of which would take up to half an hour to calculate by hand.

Accepted with 'some misgiving'

The input of the second phase consists of yarn type data, and data for each colour: the output comprises undyed yarn stock position, dyeing instructions and dyed yarn requirements and stock.

'The introduction of the system,' said the authors of the paper, 'represented a considerable upheaval in production methods, document flow and nomenclature.' The clerical and management staff have now accepted it, though with some 'residual misgiving', and are obtaining considerable benefit. There has been a decrease in work-in-progress stock, a generally tighter control over

stock and a speeding up in the flow of orders through the factory. For instance, at the end of the half year to 1st July, it was found that actual yarn stocks differed from the theoretical by only about 1%. Machine down-time due to raw materials not being available has been almost eliminated. A much improved method of quality control is now available, since yards of yarn are related directly to numbers of articles, so that any variation from the expected number of articles produced indicates an equal but opposite variation in quality of product. Lastly, preliminary time-study reports indicate the possibility that the number of machines controlled by one operator might be increased by about two to three times.'



The programme for tubing manufacture at Talbot Stead's has been broken down into these ten blocks—covering all stages from an order onwards—to enable an IBM 650 to be used

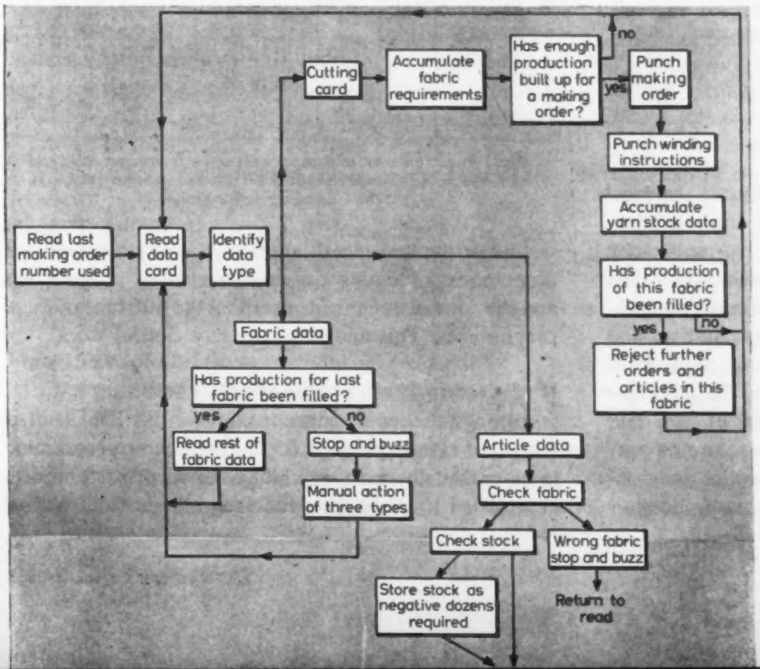
TUBING

IBM 650 forces rethinking

Attempts to develop an integrated system of data processing in a factory can reveal surprising discrepancies in previous planning methods. In a talk on the planning of tubing manufacture at the Talbot Stead Tube Co using an IBM 650 computer, R. G. Hitchcock, of Tube Investments' Computer Steering Committee, outlined some of the snags encountered in the early stages. It had been decided that the programme should select the most economical size of raw material (a short thick-walled tube usually produced by hot rolling from a pierced solid bar and known as a 'hollow') and should calculate the quantity required for a given order, making allowances for all predictable subsequent losses and defining each manufacturing operation completely and unambiguously.

A start was made on constructing flow diagrams and data tables, basing some of the calculations on maximum percentage reduction in area—the quantity always referred to as the criterion for the amount of cold work. 'On submitting them to the technical staff of the factory,' said Mr Hitchcock, 'we were very surprised to be told that few of the results would be acceptable. After some more attempts we came to the conclusion that in fact the criteria that were really used were not maximum percentage reduction in area at all, but maximum percentage reduction of thickness and maximum percentage reduction of mean diameter.' The establishment of this principle cleared away quite a number of other difficulties that had arisen. 'We took another look at the large table of hollow sizes we had envisaged,' he said. This, with four digits for outside diameters, four for thickness, three for maximum length and three for maximum weight, together with maximum permissible reduction of area with each hollow, would have occupied a large proportion of the 2000 addresses on the computer magnetic drum. 'By considering a hollow, not as an outside diameter and thickness with an associated reduction of area, but as a thickness with an associated reduction of thickness available over a diameter range, each point of which had an associated reduction of mean diameter, we were then able to construct two tables—both relatively small—which contained all the necessary data; it was then possible to go ahead on breaking down the entire job into an overall block diagram. Ten blocks were used, covering all the stages between reading the details of the order item into the system to punching output cards and printing progress records.

Working from details of orders Deuce gives making orders and winding instructions for textiles at Job White & Sons



Not as fast, but more thorough

The running time for the programme has not yet been established accurately but it is of the order of 25–30 sec per order item. 'This is, of course, long for a commercial computer programme,' said Mr Hitchcock, 'but it is largely due to the necessity of punching out 20–40 operation cards according to the number of operations involved, at the end of the programme. This card-punching, which takes place at 100 card/min, cannot be done in parallel with calculation as it would be normally. We have established that it takes about 35 minutes to plan a job manually in the same amount of detail as the computer. In addition, if we assume that the computer produces an average of 25 cards per order item with an average of 55 columns punched, these would require a further 8¼ min to key-punch and 8¼ min to verify. This comparison is between planning as carried out in this computer programme and the same job done manually. The present manual method takes about seven minutes per order item and deals only with the selection of the hollow and the definition of the drawbench and tagging operations. It does not include such a thorough examination of all possibilities as does this programme, and it results in the production of a handwritten card.'

New developments shown at the Computer Exhibition will help the works manager

Production ideas from Olympia

by **J. W. WRIGHT**, *Lecturer in Industrial Administration, Manchester College of Science and Technology*

HERE I AM GIVING NOTES ON SOME OF THE NEW EQUIPMENT which I saw at the Computer Exhibition at Olympia last month, and ideas which I learned from it, of interest to the works manager or production engineer. I do not mention the associated Business Computer Symposium, since a report on this appears on another page.

A swing towards data-processing

It is very evident from the Exhibition that British computer manufacturers are becoming increasingly concerned with data-processing. Deuce 2, Emidec 1100, Hollerith 1400, Leo 2, Metrovick 1010, Perseus and Pluto are some comparatively recent machines which are primarily designed for large scale data-processing, while the IBM 650 and 700 series with magnetic tape and disk storage and the National-Elliott 405 with magnetic film are also available. A number of smaller machines are being installed for this work, and computer manufacturers clearly are determined to sell automatic data-processing widely. Nevertheless one should not overlook the very high quality of the machines, both digital and analogue, available for scientific and mathematical work. Their reputation is well established throughout the world.

Computers help production control

To the works manager and works engineer the most important aspect of data-processing is no doubt production control. This term embraces many administrative activities. It includes: (a) what is commonly called *scheduling*—the breaking down of a production programme to determine what parts, assemblies and materials, and their respective quantities are required at different times to meet the programme; (b) *inventory control*—the determination of what supplies of each item are available so that quantities for manufacture or purchase can be authorized, taking into account procurement costs, anticipated losses and economic production factors; (c) *plant loading and utilization*—the determination of what facilities such as machines, jigs, tools, fixtures, and manpower are required and available; (d) *works documentation*—the preparation and issue of documents necessary for initiating production; and (e) *progress control*—the recording of results, the checking against schedule and information on which to base action when anticipated results are not achieved.

Computers can be used—at least theoretically—to assist production planning and control in two distinct activities. The first involves scheduling and sequencing, with mathematical calculation to decide the optimum way in which production facilities can be used. The second is the considerable analysis associated with the preparation of day-to-day manufacturing programmes and the control documents detailing the outcome of these programmes. This analysis is largely clerical work.

GAUGE REQUIREMENTS DETAIL these headings apply when R is printed in the left hand margin

INVENTORY STATUS these headings apply when I is printed in the left hand margin

	Assembly used on	Part number	Pieces per assembly		Assembly schedules: Order qty / Order no	Quantity required	Date required	Operation	Group	Dept
		Part number	Required	Ordered	Available (ordered + on hand—req.)	Economic order quantity	On hand			
R	77922	337	2	411	865 1	1730	63	285	76	221
R	77922	337	2	411	870 2	1740	83	285	76	221
R	77922	337	2	411	870 3	1740	103	285	76	221
R	77922	337	2	411	871 4	1742	123	285	76	221
R	77922	337	2	411	871 5	1742	143	285	76	221
R	77922	337	2	411	872 6	1744	163	285	76	221
R	77923	337	1	411	168 1	168	68	25	65	221
R	77923	337	1	411	168 2	168	88	25	65	221
R	77923	337	1	411	168 3	168	108	25	65	221
R	77923	337	1	411	170 4	170	128	25	65	221
R	77923	337	1	411	170 5	170	148	25	65	221
R	77923	337	1	411	170 6	170	168	25	65	221
R	77923	337	2	411	168 1	336	63	285	76	221
R	77923	337	2	411	168 2	336	83	285	76	221
R	77923	337	2	411	168 3	336	103	285	76	221
R	77923	337	2	411	170 4	340	123	285	76	221
R	77923	337	2	411	170 5	340	143	285	76	221
R	77923	337	2	411	170 6	340	163	285	76	221
I	431	337	13460	13800	2170	2380	1890			

Fig. 1 Requirements for components were printed on this type of schedule in the IBM production control demonstration at the Computer Exhibition

IBM demonstrates component scheduling

Among other demonstrations, one on the IBM United Kingdom stand provided for a production programme to be broken down, to detail the component parts needed at specified times to meet the programme. Comparison

of requirements is made against inventory to show what supplies of each item are available and what net quantities should be manufactured or purchased.

Input consists of punched cards comprising the end-product schedule, specifying item by item the product identification number, the date and quantity required and an assigned order number. The schedule is read onto the magnetic drum of the computer, 600 locations being immediately available. The system is flexible in that any number of products can be dealt with and the target for each product expressed as a series of weekly requirements for as long as a year ahead.

The mechanics of the procedure consist of matching the product schedule against a 'Bill of Materials' retained on magnetic tape, containing details of the quantities of components required for each product assembly and other pertinent data such as source and operation and department number. A feature of this tape is that it is ordered not by product assembly number but by component number, and against each component number is listed all assemblies in which that component appears. As each assembly number within the component group is read from the magnetic tape into the computer, a search is made on the magnetic drum to see if that assembly is called for in the product assembly; if so the computer calculates details of the requirement and prints them, via punched cards, on a 'Gross Requirement Detail', summarizing total requirements to meet the programme (see Fig. 1).

Level Codes. The time for manufacture of components and their assembly is broken down into periods which are termed *levels*. The *level used code* is the level at which a component enters a specified assembly process. The *low level code* is the lowest level of component entry, that is the earliest time at which a component is ever required. The code is obtained by a standard punched card procedure and stored on the 'Bill of Materials' tape.

Action is taken at low level so that if the level being processed by the computer coincides with the low level of the particular component, the total requirements of that component, whatever assembly it might appear in and at whatever level it is used, are consolidated. This enables a comparison with the inventory, details of which are on magnetic tape. If necessary, order cards are punched, and the inventory record updated. A summary is printed of the inventory states (see Fig. 1).

If the levels do not coincide, the computer records the details on a third magnetic tape, the 'Gross Requirements Tape', for re-entry and processing at the reset level. It makes provision for producing the necessary information for shop loading and raw materials analysis.

Machine tool and process control

Not a great deal was to be seen at the Exhibition under this heading, since computers on show were mainly for data-processing and scientific research.

Ferranti were showing the prototype and announced a new transistorized digital computer (Fig. 2) measuring only 4 ft × 4 ft × 2 ft, the size of two small filing cabinets and designed primarily for process control (see *News Round-up* this month).

Recent development in the Ferranti system of machine-tool control enables a separate digital differential analyser, working in conjunction with a general-purpose computer, to prepare the machining information for generating complicated three-dimensional contours. Such an analyser essentially carries out a simple integration process with a greater economy in machine time than a

Fig. 2 Ferranti have designed this transistorized computer for controlling industrial processes and power stations. It uses magnetic cores and printed circuits extensively

general-purpose computer. It can be used for directly controlling a digital plotting table designed to plot at high speed two-dimensional digital information.

Examples of three-dimensional machining problems now being tackled are the production of turbine blades, compressor blades, water runners and ships' propellers. Thus a three-blade ship's propeller of 4 ft diameter can be completely machined in 15 hours, the information being taken, without drawings, direct from the hydrodynamicist's figure.

Mullard Equipment have a precision measuring transducer which can be used in analogue digital systems of machine tool control. One model automatically positions a tool carriage over 30 in. × 20 in. within ± 0·002 in. British Thomson-Houston showed equipment which included a control desk and card reader for a co-ordinate setter, tracer and co-ordinate heads, and their latest form of measuring unit, the Helisyn, for positioning tool tables to within 0·0001 in. This is a null device which accepts digital control information and will be used in the BTH system of computer control of continuous-path machining.

Computers will bring problems too

Clearly we have reached a new stage in the application of computers. Computer equipment of great potential is now coming off the production lines in this country, and will throw up a host of industrial problems which I shall not attempt to discuss here. But I trust that by the next Computer Exhibition we shall be well on the road to their solution.

Pandemonium's offspring may be part of tomorrow's control systems

Machines that try to think

E. A. Newman, Deputy Superintendent of the Control Mechanisms and Electronics Division of the National Physical Laboratory, reports on the recent symposium at the Laboratory. He outlines some scientific excursions into the tantalizing no man's land between the brain and the computer which were revealed at the meetings

THE NATIONAL PHYSICAL LABORATORY SYMPOSIUM ON 'The Mechanization of Thought Processes' at the end of November covered General Principles, Automatic Programming, Language Translation, Speech Recognition and Learning, with sessions for biologists, for psychologists and for industry.

Recognizing characters

Dr W. K. Taylor (London University) described a process for recognizing letters or figures. He divides his observational area into sections. Associated with each area there is a sub-unit which computes how much of an observed letter falls into the area. The machine contains a set of superior units, one for each character to be distinguished. These compute the sum of the suitably weighted outputs of each sub-unit—the set of weightings varying from one to another. In this way they compute a signal. From these signals a 'decision maker' selects the largest. The weightings are 0 or 1, and are obtained from templates, whilst the outputs of the sub-units can take on any value. Dr Taylor considered the latter feature important. (See also *News Round-up*, November, p. 230.)

Mr R. H. Tizard (London School of Economics) tested a similar technique—with a simple learning process added—on a Deuce computer. Neither Dr Taylor's apparatus nor Mr Tizard's programme was perfect—but each gave much hope for the future.

Saving time on programming

The symposium contained four papers on automatic programming aids for use with automatic digital computers. Control engineers might wish to make computer programmes to test out theoretical control systems or perhaps to include the computer in the control apparatus. Since they would not wish to waste too much time learning to programme, automatic programming aids might well appeal to them.

Usually such systems have some of the following features:

1 Machine operations can be specified in a language other than the accepted machine code.
2 Instructions about operations can be specified in an order different from that required by the machine.
3 Labels can be used for variables other than the addresses of their machine locating, the latter being determined automatically.
4 Groups of instructions can be called in by use of a code name for the set.
5 A set of operations on a set of groups of variables can be specified by naming the set of operations, and the set of groups in a simple way, the system looking after any necessary organizational instructions.

Since under 1 and 2 the user has to use a specified language and order—though maybe more natural than machine ones—and 4 can be done clerically provided standard instruction sets are available; only 3 and 5 are of undoubted help to a programmer. Automatically produced programmes cost expensive machine time to produce, and are usually not so economical in machine time as man-made ones.

The system put forward by Mr R. A. Brooker (Manchester University) was the most elementary, that by Dr Grace Hopper (Remington Rand University, USA) intermediate and that by Mr J. Backus (IBM, USA) very comprehensive. That put forward by Dr A. P. Ershov (USSR) was for a certain type of mathematical equation only. It was perhaps, in its limited scope, in advance of the other systems; but it was only a projected system. The others are going concerns. Great use is made of automatic programming techniques in the USA. They are perhaps not quite so valuable in Britain, where wages are very much lower, and, dare one suggest, the general standard of education might be rather higher.

Only a dream?

Dr F. Rosenblatt (Cornell University, USA) described a learning device called a Perceptron. The name Perceptron is used for a large number of devices, all still more

or less in the idea stage. They all have in common a primary sensing network, consisting in one case of a matrix of photocells, an association matrix, and a response unit, which might be randomly connected to the association matrix. The sensing elements are connected to the association elements in a random way. There is a feedback arrangement from output to input of the association network, via the response unit, which acts to reinforce association cell activity should the response be a desired one. Great things are claimed for the Perceptron, and perhaps it will prove the control engineer's dream, but too little has been said to enable one to judge.

Demons that read Morse

Starting from scratch the best learning machine could scarcely do as well as a new-born babe. Perhaps learning systems are best employed improving control systems that work without them.

Such a learning system was described by Dr O. Selfridge (MIT, USA) in vivid imagery. He called it Pandemonium, and had designed it to distinguish between different situations. He described as an example its use for recognizing man-made Morse code. In discussion it was suggested that it was easy to do this by a machine working on well-known statistical techniques. Dr Selfridge claimed that in fact men made many mistakes when reading Morse and that alone of all the mechanical systems that have been tried, his proved better than a human operator.

Pandemonium operates at three levels. It contains *computing demons* of various kinds which send out signals only if incoming signals meet certain criteria.

At a second level are *cognitive demons*, one for each state to be distinguished, which measure how far the outputs of the computing demons fit this state. Each cognitive demon gives a weight to each 'computing demon' and adds the weights of those with signals. The machine improves its performance by adjusting the weights so as to give the biggest distinction between states—the correctness of its decisions are at first fed in—and by replacing computing demons which prove of little use by new ones. The best weights are found by a 'hill-finding' technique similar to that used by Dr Box in the chemical manufacturing industry. New demons are made by making small adjustments to good ones, or combining the properties of good ones.

Pandemonium has worked admirably, and though the task it has solved is rather trivial, the technique it uses is one which could well prove of value to the control industry.

Hedonistic, yet essentially rational?

Another learning system making use of much of what is already known is that described by Dr A. M. Andrew (NPL). Dr Andrew proposed that his machine should start its control on the assumption that the important variables were connected by a known functional relation of polynominal form. His apparatus would have means of finding the degree of 'hedony'—the extent to which the control failed to reach its goal. It would learn by making small trial-and-error changes in the parameters of the assumed relationship and selecting those changes which, averaged over a reasonable period of time, would reduce hedony.

One remarkable feature of nervous systems is their stability. In them all the more vital functions are protected against interference and still work in a patient under deep anaesthesia. A man behaves fairly rationally even when a high percentage of his neurons have been put out of action by alcohol.

This property is one we would wish to have in automatic control systems. Should breakdowns in apparatus cause control to coarsen, it might not matter, but faults must not result in catastrophe.

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Pandemonium's offspring may be part of tomorrow's control systems

Machines that try to think

E. A. Newman, Deputy Superintendent of the Control Mechanisms and Electronics Division of the National Physical Laboratory, reports on the recent symposium at the Laboratory. He outlines some scientific excursions into the tantalizing no man's land between the brain and the computer which were revealed at the meetings

THE NATIONAL PHYSICAL LABORATORY SYMPOSIUM ON 'The Mechanization of Thought Processes' at the end of November covered General Principles, Automatic Programming, Language Translation, Speech Recognition and Learning, with sessions for biologists, for psychologists and for industry.

Recognizing characters

Dr W. K. Taylor (London University) described a process for recognizing letters or figures. He divides his observational area into sections. Associated with each area there is a sub-unit which computes how much of an observed letter falls into the area. The machine contains a set of superior units, one for each character to be distinguished. These compute the sum of the suitably weighted outputs of each sub-unit—the set of weightings varying from one to another. In this way they compute a signal. From these signals a 'decision maker' selects the largest. The weightings are 0 or 1, and are obtained from templates, whilst the outputs of the sub-units can take on any value. Dr Taylor considered the latter feature important. (See also *News Round-up*, November, p. 230.)

Mr R. H. Tizard (London School of Economics) tested a similar technique—with a simple learning process added—on a Deuce computer. Neither Dr Taylor's apparatus nor Mr Tizard's programme was perfect—but each gave much hope for the future.

Saving time on programming

The symposium contained four papers on automatic programming aids for use with automatic digital computers. Control engineers might wish to make computer programmes to test out theoretical control systems or perhaps to include the computer in the control apparatus. Since they would not wish to waste too much time learning to programme, automatic programming aids might well appeal to them.

Usually such systems have some of the following features:

1. Machine operations can be specified in a language other than the accepted machine code.
2. Instructions about operations can be specified in an order different from that required by the machine.
3. Labels can be used for variables other than the addresses of their machine locating, the latter being determined automatically.
4. Groups of instructions can be called in by use of a code name for the set.
5. A set of operations on a set of groups of variables can be specified by naming the set of operations, and the set of groups in a simple way, the system looking after any necessary organizational instructions.

Since under 1 and 2 the user has to use a specified language and order—though maybe more natural than machine ones—and 4 can be done clerically provided standard instruction sets are available; only 3 and 5 are of undoubted help to a programmer. Automatically produced programmes cost expensive machine time to produce, and are usually not so economical in machine time as man-made ones.

The system put forward by Mr R. A. Brooker (Manchester University) was the most elementary, that by Dr Grace Hopper (Remington Rand University, USA) intermediate and that by Mr J. Backus (IBM, USA) very comprehensive. That put forward by Dr A. P. Ershov (USSR) was for a certain type of mathematical equation only. It was perhaps, in its limited scope, in advance of the other systems; but it was only a projected system. The others are going concerns. Great use is made of automatic programming techniques in the USA. They are perhaps not quite so valuable in Britain, where wages are very much lower, and, dare one suggest, the general standard of education might be rather higher.

Only a dream?

Dr F. Rosenblatt (Cornell University, USA) described a learning device called a Perceptron. The name Perceptron is used for a large number of devices, all still more

or less in the idea stage. They all have in common a primary sensing network, consisting in one case of a matrix of photocells, an association matrix, and a response unit, which might be randomly connected to the association matrix. The sensing elements are connected to the association elements in a random way. There is a feedback arrangement from output to input of the association network, via the response unit, which acts to reinforce association cell activity should the response be a desired one. Great things are claimed for the Perceptron, and perhaps it will prove the control engineer's dream, but too little has been said to enable one to judge.

Demons that read Morse

Starting from scratch the best learning machine could scarcely do as well as a new-born babe. Perhaps learning systems are best employed improving control systems that work without them.

Such a learning system was described by Dr O. Selfridge (MIT, USA) in vivid imagery. He called it Pandemonium, and had designed it to distinguish between different situations. He described as an example its use for recognizing man-made Morse code. In discussion it was suggested that it was easy to do this by a machine working on well-known statistical techniques. Dr Selfridge claimed that in fact men made many mistakes when reading Morse and that alone of all the mechanical systems that have been tried, his proved better than a human operator.

Pandemonium operates at three levels. It contains *computing demons* of various kinds which send out signals only if incoming signals meet certain criteria.

At a second level are *cognitive demons*, one for each state to be distinguished, which measure how far the outputs of the computing demons fit this state. Each cognitive demon gives a weight to each 'computing demon' and adds the weights of those with signals. The machine improves its performance by adjusting the weights so as to give the biggest distinction between states—the correctness of its decisions are at first fed in—and by replacing computing demons which prove of little use by new ones. The best weights are found by a 'hill-finding' technique similar to that used by Dr Box in the chemical manufacturing industry. New demons are made by making small adjustments to good ones, or combining the properties of good ones.

Pandemonium has worked admirably, and though the task it has solved is rather trivial, the technique it uses is one which could well prove of value to the control industry.

Hedonistic, yet essentially rational?

Another learning system making use of much of what is already known is that described by Dr A. M. Andrew (NPL). Dr Andrew proposed that his machine should start its control on the assumption that the important variables were connected by a known functional relation of polynominal form. His apparatus would have means of finding the degree of 'hedony'—the extent to which the control failed to reach its goal. It would learn by making small trial-and-error changes in the parameters of the assumed relationship and selecting those changes which, averaged over a reasonable period of time, would reduce hedony.

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NEWS ROUND-UP

from the world's industries

Users step in

More cooperation between instrument maker and instrument user was the keynote of the Seventh Annual Convention of the Scientific Instrument Manufacturers' Association, held last month at Harrogate. Some 250 delegates attended and user industries were directly represented for the first time at a SIMA Convention. The committee had devised a clever pattern of panel discussions for the main business of the Convention, which allowed four aspects of instrumentation (laboratory, plant, maintenance and future trends) with four industrial groups (iron and steel, textile and fibres, oil and chemicals, fuel and power). These were conducted in four sessions of four simultaneous discussions: each panel was chaired by an instrument maker and the opening speaker was a user.

'Extraction' is necessary. Some lively discussions took place in the oil and chemicals panel, which was always well attended. The first of these, on plant instrumentation, was opened by Mr C. W. Munday (Distillers Co). He wanted smaller process instruments. Flameproofing was easier in large ones, but often their thermal inertia was prohibitive. He asked why British ideas frequently had to travel across the North Sea or the Atlantic before being incorporated in plant instruments, quoting as two examples of this, the infra-red gas analyser and the gas chromatograph. He wanted more adequate data sheets issued with instruments, showing long-term stability, effect of pressure and voltage variation etc—information that could 'often be extracted from the manufacturers personally.'

Back more hunches. Mr Colvile (Hilger & Watts) asked for standard sampling arrangements for analysis instruments, to formulate which, Mr Tallantire (ICI) disclosed, the SIT are considering setting up a committee. Emphasizing that the instrument maker must know his plant, Mr Little (Distillers Co) pointed out the merits of a user turning manufacturer and developing his own instruments. He pleaded strongly for a central organization, set up by the instrument industry, to evaluate instruments. Many speakers discussed the slow development of new ideas—the best way of speeding a project up was to put one man in charge of it from research right through development and on to post-production modifications. Mr Young (ICI) thought that, despite a sprinkling of progressive firms, too many instrument makers had no faith in instrumentation—they should not always wait in developing an instrument 'until they had fifty orders for it in sight.' Mr Goudime (Electronic Instruments) rejoined that instrument firms will always back a limited number of hunches —but not too many.

In-line for steel Opening the discussion on plant instrumentation at the iron and steel panel, Mr Carlisle (BISRA) pointed out that very few in-line quality analysis instruments were fitted in iron and steel works. Further development of automatic gauges for hot-strip rolling mills was needed, and there was as yet no device for continuous in-line dimensioning of hot rolled section.

Make them reliable Nuclear instrumentation must be more reliable than it is at present, said Mr Stonehouse (GEC) at the plant instrument session of the fuel and power panel. He cited three types of instrument needing development: less restrictive gas flowmeters; CO_2 moisture meters measuring down to 100 parts in 10^6; and better data-handling equipment.

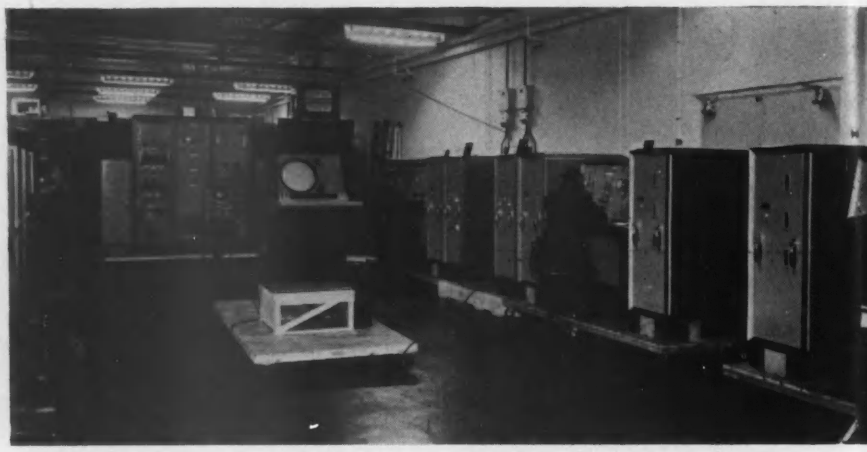
———AIRCRAFT———

Italians get new radar trainer

The first Solartron Radar Simulation System has been completed and will be delivered to the Italian army authorities during December. Costing £125,000, it employs analogue computers to simulate both targets, radar stations, attacking and defensive aircraft and electronic counter-measures. The Italian army will be able to carry out realistic training and exercises at low cost and two additional advantages are more complete security and non-interference with civil air routes.

The system consists of a number of desk consoles with control panels, a central rack system for main supplies and switch controls, and two control equipments each fitted with radar PPI's (Plan Position Indicators) on which aircraft and electronic radar defence measures are seen as blips and marks. Each desk console is flanked by two analogue computers and contains two identical control panels representing two aircraft. The pilot sits opposite his panel: if necessary one pilot can control two aircraft.

One side computer converts the track information fed from the desk panel into the polar co-ordinates used in radar systems and then produces video radar pulses, delayed and gated by antenna function generators, and feeds them to video mixers which combine all the console outputs in the central control rack. There are seven consoles, making fourteen aircraft, which may be allocated to be belligerent or interceptor aircraft as required. In addition four targets are 'window' jammers which simulate the dropping of reflecting metal foil, and two are parachuted noise jammers. The simulators for these are located in the side



COMPUTERS TAKE SIDES While 'pilots' control the 'aircraft' consoles (left and right), analogue computers by their sides simulate radar installations in the Solartron system. Progress of the exercise is watched on display consoles by controllers in charge of each 'side'

computers and their effects fed into the main system. A flying-spot scanner moves across a polar and cartesian plotting table; fogged photographic plate is inserted, and a sapphire needle inscribes the track of the aircraft dropping window. The signals from the flying-spot scanner are processed by suitable noise and function generators to simulate video response from metal strips of varying characteristics and fed to the PPI's of the main controls. The X and Y co-ordinates of wind velocity are dropped in electronically, and the net result is simulation of the drift of metal strips by the wind in the sky.

Two large consoles stand by themselves behind the computers or may be installed away from the aircraft console room. They have PPI's on which the aircraft can be seen in their courses, and the effect of window and noise jammers viewed on the location of the aircraft by the simulated radar system. One console is fitted for fighter and bomber control, and the other can be either fighter or bomber. The controller for each console is in communication with his pilots through the usual headphone-throat microphone arrangement, which plugs into a socket on the desk-consoles.

VHF control for cranes now

Radio remote control equipment is now being used in Norway by the Scandinavian Airlines system to control one of their new overhead travelling aircraft cranes. It was developed by Munck International of Bergen and consists of a 156–174 Mc/s VHF transmitter and receiver together with a decoding system which is installed on the crane. Its use enables engineers to operate the crane from ground level at any convenient point while they are installing aircraft components, so that the factor of uncertainty involved in the conventional use of signals is eliminated. If desired it can be used to control a crane some distance away—maximum range goes up to 2 or 3 miles.

The transmitter is built up of miniature components and contains 18 transistors and 7 sub-miniature tubes; an accumulator gives the necessary power. A control stick with a pushbutton for each of eight crane motions is connected to the transmitter. When one or more of the buttons is depressed corresponding frequency sensitive relays in the decoder of the receiver on the crane are actuated. These are matched to the power output transformer of the receiver, and they fire trigger tubes which operate the power controls of the crane via more relays.

Other possible applications include loading and unloading ships. Here the crane operator could take the talleyman's place on deck and direct the loading and unloading himself. By walking from the railing to the hatch, carrying the transmitter on his back, and keeping an eye on the cargo when it is transferred from quay to cargo hole or vice versa, the safety of loading and unloading could be considerably increased.

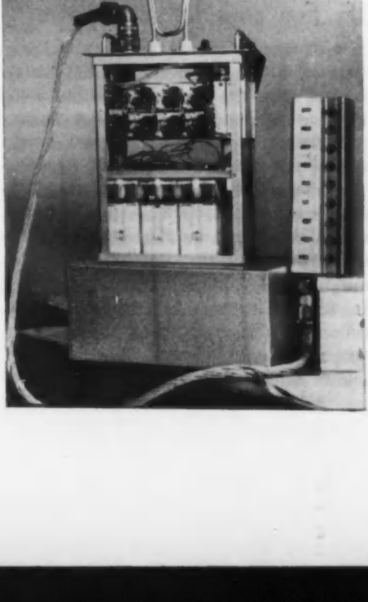
——TRANSPORT——

Ironing out the kinks

An electronically controlled machine for the automatic trueing of bicycle wheels has been developed by the British Cycle Corporation in conjunction with Tube Investments Ltd. It was shown for the first time on the Phillips stand at the Earls Court cycle show. The wheel, roughly laced but with the spokes still loose, is placed into the machine by the operator, who then merely presses a button and takes no further part in the operation until the machine has finished trueing and testing the wheel one minute later. This is a task which has always proved extremely difficult to mechanize, being normally done by highly skilled operators after a long period of training.

When the wheel is placed in the machine it is automatically lowered horizontally into a bed incorporating a ring of 40 electric motors; each one is individually controlled, and tightens one spoke only. The motors drive spanners, and when these have gripped the spoke nipples a magnetic sensing head is lowered on the end of an arm which is then rotated at high speed just above the rim of the wheel—the head scanning the rim all the time to detect any divergence from the true circle. The information from this inductive magnetic head is fed into two control cubicles at the rear of the machine, where it is translated by electronics into individual instructions for each one of the 40 electric motors tightening the spokes. The machine is so designed that the only forces acting on the rim are those imposed by the spokes themselves, so that when the wheel is true in the machine it will stay true when removed from it. The spokes are tightened

Incorporating 18 transistors and 7 sub-miniature tubes this small transmitter is carried on a man's back while he uses the control stick on the right to operate one of Scandinavian Airlines' new aircraft cranes



Bicycle wheels at Phillips are now trued automatically by means of the magnetic sensing head which rotates just above the rim and sends instructions to the electric motors tightening the spokes

until the correct overall tension has been established, and when the trueing is completed the inductive head continues to rotate as a final check that the operation is completed. Once it is satisfied that each spoke is under the right tension the rotation stops and the sensing head is withdrawn. The spanners then rotate slightly to free the spokes, and the wheel is released ready for removal.

The operations are complicated by the fact that the variations in dimensions of the rims are such that the machine has to determine its own tensioning limits before trueing can start. Nevertheless, it still trues and tests at the rate of one wheel a minute, the wheel being true to within 0·030 in. This is a much faster rate of production and a greater degree of accuracy than could be achieved by even the most skilled wheel builder. It is unlikely that the machine will be offered for sale. 'It gives us a big advantage over the other cycle manufacturers,' said a Phillips spokesman.

——COMPUTERS——

NPL plays a winner

By releasing news of Ace, its latest brain child, some ten days before the Computer Exhibition, the NPL emphasized that industrial firms do not have a monopoly of successful computer development. Built by the Control Mechanisms and Electronics Division of the Laboratory, Ace is the fruition of eleven years' work on digital computers at the NPL, which was started by the renowned Dr Turing in the early post-war years. The machine is intended for mathematical work and has recently been handed over to NPL's Mathematical Division, who will use it for calculations

such as those involved in aerofoil design or temperature distribution in a nuclear reactor. It was developed from the Pilot Model Ace completed in 1951 and is one of the fastest in the world, with a working store (mercury delay lines) of 800 words and a backing store of 32,768 words. In contrast to EDSAC II at Cambridge it operates serially. Fed by punched cards, it will read 7000 bits and 7·5 cards per second. The techniques of using the computer are at least as important as its actual design and much of the NPL's work will be on methods of carrying out high-speed calculations.

At a recent Press conference to introduce Ace, Dr Uttley, head of the CMF Division, described it as being of the 'second generation of computers'. The third generation involves transistors and ferrite cores. But it is unlikely that the NPL will itself build any more large computers. Computer techniques —rather than the computers themselves— are now the order of the day: one of the most important being investigated is low-temperature stores (*News Round-up* Nov).

NPL'S GIANT One of the biggest and fastest digital computers in the world, the National Physical Laboratory's Ace consists of six cubicles facing the control desk and printer on the left. It employs conventional rather than plug-in construction and motorized doors are raised by pushbutton to give access for maintenance

Ferranti's unveil PCTC

A prototype of a transistorized digital computer designed to provide fully automatic control of many industrial processes has been made by Ferranti Ltd; production models are expected to be available in 1960. This will be the first time in the UK that a computer of this type designed for process control will use transistors instead of thermionic valves and, as a result, it will only measure about 4 ft × 4 ft × 2 ft. It has been named the PCTC—Process Control Transistor Computer. The transistor logical circuits have been tested out and an experimental model has controlled a machine which simulates a plant process for more than 2000 hours operation without component failure, say Ferranti. Vibration and temperature tests have also been carried out to simulate the most rigorous conditions the computer is likely to meet in industrial use.

The computer is being specifically developed as the centre unit in control systems for a variety of industrial processes in the power, chemical, oil, gas and steel industries. Babcock and Wilcox and their associates Bailey Meters and Controls are currently investigating with Ferranti the feasibility of using it for the control of boilers during start-up and shut-down. Its price will probably be in the £20,000–£50,000 range, depending on the size of the installation.

—CEMENT—

US firm goes for auto-control

The Riverside Cement Company of California, US, has bought an RW-300 digital control computer system as the first step toward fully automatic control of a cement manufacturing plant, J. M. Kinard, president of the company, announced recently. The computer will guide the operation of a completely mechanized rock blending facility now being installed at Riverside's Oro Grande plant, and also provide information to control quarrying operations. In addition to control functions, it will collect and analyse data needed in planning automatic control systems for the entire cement manufacturing process. Extra kilns are to be installed at the plant and the computer will also log data from these. It will provide continuous records of such variables as temperature, fuel gas, gas flow and rotation speed.

The initial RW-300 system costs about £46,000. It will be installed in the spring, and its first job will be the quarrying and stockpiling operations. The computer will keep track of the amount, chemical composition, and point of origin of thousands of tons of rock and other raw material loaded into Riverside's new blending facility. It will periodically calculate how much of what kinds of materials should be added to the pile to obtain the proper proportion of cement-making ingredients, thus indicating the most economical action to take on the basis of such factors as hauling distances and cost of quarrying in various areas. Analysis of rock samples will continue to be accomplished with an X-ray spectrometer at the Oro Grande plant, but the computer will automatically bring in data from the spectrometer and will perform all necessary calculations, including calibrations.

The RW-300 is the first digital computer in America to be designed specifically for automatic process control, data logging, and test facility operation. It is transistorized, and built-in analogue-digital conversion equipment allows it to be connected directly to measuring instruments and control devices.

—ATOMIC ENERGY—

Cutting the hazards

A simulator for training operators of the first commercial nuclear power stations is now under construction by Elliott Bros (London) Ltd for the Central Electricity Generating Board. It will be arranged to simulate the gas-cooled graphite-moderated type of plant—installation is due next July at the site of the Berkeley station—but the unit system of construction is employed so that it could be used with some modification on the other stations of this type or even on future fast breeder reactors. Apart from the convenience of training technicians without having to use an actual reactor, operations which might be extremely hazardous on a real reactor can be simulated.

A control desk, a computer cabinet and two wall mounting boiler panels make up the simulator. It is based on an electronic analogue computer, and the quantities simulated are all represented by voltages in the range −100 to +100 V d.c. Accordingly, instruments on the desk and boiler panels take the form of appropriately scaled voltmeters and self-balancing potentiometers.

The control desk is of similar shape and size to that in an actual reactor. All the controls required for the operation of the plant and all the instruments except those referring to the steam and water side of the boilers are mounted on the desk: indicators

and recorders show control rod positions, reactor power level on linear and logarithmic scales, power deviation from a chosen value, doubling time, coolant flow and fuel element temperature, coolant inlet and outlet temperatures, moderator temperature and the generator loads. Amongst the controls are raise/lower switches controlling reactor shut-off rods and control rods, blower speed, turbine steam valves, and boiler feedwater valves.

METALS

Control by dewpoint

The control of carbon potential in furnace atmospheres should be made easier by a new set-up demonstrated at the recent Electro-heat and Productivity Exhibition in Glasgow. Developed by Birlec Ltd, it makes use of the fact that the carbon potential of the atmosphere in a steel heat-treatment furnace, which determines its carburizing or decarburizing effect, can be related to the moisture content of the gas, measured by its dewpoint. The sensitive element which detects changes in dewpoint is a device whose electrical resistance changes in accordance with the humidity of the surrounding atmosphere, and its sensitivity is said to be such that the furnace atmosphere can be continuously controlled at a composition to suit the type of steel being treated and to obtain the desired metallurgical result. The electrical impulse from the element is translated into air pressure, which is used to control the supply of hydrocarbon gases to the atmosphere generator, by means of a metering valve.

NEW SYSTEM

New ideas in furnace control

A new system of programme control for the temperatures of small electric furnaces used for testing metals at Stewarts & Lloyds was shown to CONTROL during a recent visit. It employs strip charts on which thick lines representing temperature variations are drawn in graphite ink. A sensing head with a platinum brush hunts about the right-hand edge of the ink strip, and produces an a.c. signal proportional to the position of the head. This signal can be used as the desired value in an electrical temperature controller, which regulates variable resistors in the furnaces. Each furnace has its own strip chart for programme control, and the actual furnace temperatures are recorded on a multi-point recorder, with different coloured inks.

The apparatus is doing useful work in the new metallurgy laboratory, which with instrument, engineering, chemistry and photography laboratories are housed in the new buildings of the Research and Technical Development Department.

IN BRIEF

● **Systems** The Baldwin Instrument Co announce that their team of application and design experts has been expanded. Free advice is available on pneumatic, hydraulic or electronic systems.

● **Faraday lecture** First 'performed' in Swansea last month, the 1958–59 Faraday Lecture of Dr Thomas (Unilever's Control Manager) on 'Automation' is a *tour de force*, lavishly illustrated by colour films and ingenious working models. Process control, machine tool control, automatic inspection, sorting, weighing, packaging, computers—all are lucidly explained. Although primarily for the layman, Thomas's brilliant show should not be missed by control engineers. It goes on tour again next month and ends in Edinburgh.

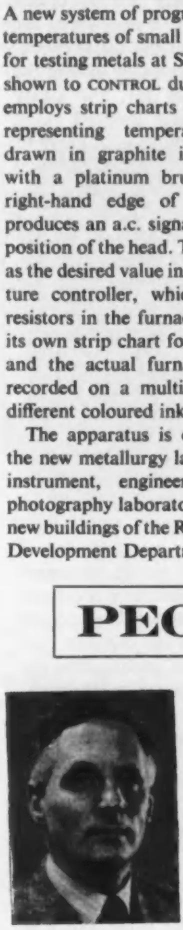
● **Railways** The third and final stage in the conversion to completely automatic signalling of junctions on the in-town sections of London Transport's Northern Line was brought into use at Euston on Sunday, 16th November.

● **Components** Kinetrol Ltd of Farnham, Surrey, are developing an electropneumatic rotary actuator which measures only $3\frac{3}{4} \times 2\frac{1}{4} \times 3\frac{1}{4}$ in. but gives a torque of 60 lb/in. Other figures are: input air pressure 80-100 lb/in², travel 90-110 deg rotation, electrical input 230 V a.c. or 24-28 V d.c.

PEOPLE IN CONTROL

The de Havilland Aircraft Co's Board of Directors should be the stronger now that **John Cunningham,** their Chief Test Pilot, and **C. T. Wilkins,** the company's Chief Designer, are joining the Board. Both were deeply immersed in the Comet project and are, of course, concerned with the design of the DH 121 jet for BEA. The company's new General Manager is **R. G. McCoy.** DH Engines have also made two additions to their Board, **W. F. Shaylor,** an ex-Airspeed man, becomes Sales Director, and **Professor A. D. Baxter,** who became Deputy Principal of the College of Aeronautics, Cranfield, in 1954, becomes Chief Executive Rocket Division and Nuclear Power Group.

Professor E. E. Zepler—ex-Telefunken, ex-Marconi's and now occupying the Chair of Electronics at the University of Southampton—will be President of the British Institution of Radio Engineers during 1959. He is probably best known for his standard work on radio receivers, 'The Technique of Radio Design.' Professor Zepler told CONTROL that he was most honoured and knew the Brit IRE would have a great future working together with other societies.



PROF ZEPLER
Electronics Chair and Brit IRE Presidency

Mervyn Instruments, the scientific instrument people, have strengthened their sales force with Messrs **V. M. Farrant** (Sales Promotion Manager), **P. M. Bartlett** (Divisional Sales Manager), and **J. A. Shelton** and **A. E. Deslandes** (Technical Liaison Officers). Farrant and Bartlett are well known in the petroleum industry and will be concerned with new Mervyn instruments such as their infra-red spectrometer and square wave polarograph. The duties of the Technical Liaison Officers will include liaison with various official bodies, such as AERE, to expedite development of commercial instruments.

Farrant told CONTROL that the heavy industries needed accuracies of the order of one in 100 million just as much as the laboratory or research organization. "They should have such accuracies, particularly in production control."

The Industrial Control Department of Metropolitan-Vickers should welcome the appointment of **R. F. Mansfield** as Assistant Sales Manager of the Department. He joined M-V in 1937 as a college apprentice. **F. Crowther,** who becomes Assistant Chief Engineer (Design) Industrial Control Department, joined as an apprentice in 1928.

R. F. MANSFIELD
Will sell industrial control

The new Applications Engineer of West Instrument is **J. C. Driver,** formerly their Chief Inspector. The study of possible further applications of West temperature controllers will be his main concern.

Pick-off

by 'UNCONTROLLED'

MR R. BARRINGTON-BROCK told us at Harrogate last month that SIMA is likely to change its full name to the 'Scientific and Industrial Instrument Manufacturers' Association', though, if so, its short title will remain SIMA. Now that SIMA is gaining a greater industrial emphasis and taking in, for example, more pneumatic instruments, what of the British Industrial Measuring and Control Apparatus Manufacturers' Association? Surely a greater impact could be made on potential buyers of instruments and control gear if the two organizations joined forces. Admittedly they do this for really important instrument events such as the IEA Exhibition, but to maintain separate permanent staffs and have committees tackling similar problems cannot be economic nor efficient. The manufacturers' association is not the sort of organization that benefits from competition. Moreover, present-day structure of an industry should not be governed too much by past history. I suggest that SIMA and BIMCAM should open informal talks to see if they can sink any differences and evolve a joint organization—perhaps with sections as in the British Electrical and Allied Manufacturers' Association—that would be more powerful than either of them separately.

AMID the publicity the Olympia Exhibition has given to commercial computers the successful completion of the NPL's giant, Ace, has not perhaps received all the notice it would have in less computer-swamped times. Primarily for use by NPL's Mathematical Division, Ace is the outcome of twelve years' development work, and quite apart from its design is an engineering achievement by the NPL workshops. To help those who get confused over the card-playing and classical terminology used for computers, let me recall that the first electronic computer the NPL built was the Pilot Model Ace (now in the Science Museum) and this was later engineered by the English Electric Company into Deuce. Ace proper is generously housed at Teddington in an old wind tunnel, and appropriately enough it will certainly be used for aircraft design calculations.

With its large motor-driven doors (see *News Round-up*), the servicing philosophy for Ace is to replace faulty components *in situ*. Units are not duplicated, but the usual checking procedures take place during the first hours of each day, and faulty units can be speedily isolated. As it happens, the computer is unlikely to be worked more than about 75 hours per week. Although Ace's main customer must clearly be the NPL's Mathematical Division, I suggest that the Laboratory might well introduce shift work and hire the computer out to industrial or other organizations. This has, I believe, been done regularly on the Teddington Deuce. Moreover Ace has cost the taxpayer about a quarter of a million pounds.

LAST month I was in Swansea to hear the first delivery of Dr H. A. Thomas's 1958–59 Faraday Lecture on 'Automation'. 'Hear' and 'Lecture' are really not appropriate —'see' and 'Show' would be nearer the mark. For this lecture is spectacular: lavishly designed working models disclosed behind huge crimson curtains; a large cinema screen above the models showing colour films throughout much of the lecture; a console in the 'orchestra pit' from which Dr Thomas's main assistant controls demonstrations and checks timing; and curtain calls at the end for all the assistants taken with professional actors' precision. I am told that Unilever have not yet worked out how much the company has spent on equipment for the show, but it is reputed to be at least £10,000. Many other firms, including particularly Elliott Brothers and ICI, have helped in its preparation.

The Faraday Lecture is arranged annually by the IEE to tell the public about recent advances in electronic engineering. Nowadays it is always enthusiastically supported wherever it is given. But who attends it? I understand that a large percentage of those taking tickets are engineers or people with some scientific interest. The lecturer, however much he is appreciated, preaches largely to the converted. This problem indeed faces all those who try to do missionary work to make Britain more technically minded. For example, how many readers of *The New Scientist* are genuinely non-scientific—the type of reader to whom the paper was originally addressed?

However that may be, he will be a dull-witted person who sees this year's Faraday Lecture and is not enthralled. I, for one, am going to have a second helping of it when it comes to the South Bank in January —if I can get a ticket. Dr Thomas tells me that the models will not be broken up at the end of his tour of thirteen towns. This is good news, for Dr Thomas's show will plainly have great entertainment and educational value long after March 1959.

'THE Guinness Book of Records' fascinated me, when it was first published three years ago, and I have enjoyed myself dipping into the revised third edition, which has appeared in the last month or two (Guinness Superlatives Ltd, 10s. 6d.). It is a remarkable commentary on the individuality of man and his environment and achievements. Although the book has been brought up-to-date and there is a twenty-one page section on 'The Mechanical World', instrumentation and control are hardly mentioned. The six-year-old Russian BESM computer gains a highly misleading mention on the score of being the world's largest in terms of physical dimensions, and missiles get a look in, but not much else. So the book could be real 'escape' reading for the control engineer this Christmas.

SOME readers of *Pick-off* may regard this as the season for brain teasers; in case they are short of something to sharpen their wits on, I give this simple puzzle:

> Suppose the publishers decided to change the monthly date of publication of NUCLEAR POWER (CONTROL's stable mate) to the Thursday before the second Wednesday each month, as from January 1959. When would be the next two consecutive issues in which the dates of publication differ numerically by a perfect number?

I offer a prize of the current issue of NUCLEAR POWER to anyone who sends me (c/o CONTROL) the correct answer before Christmas. And on that hopeful note I should like to close by wishing all readers of CONTROL a Happy Christmas and Successful New Year.

New for Control

A monthly review of system components and instruments

PRESSURE STANDARD

wide range, rapid response

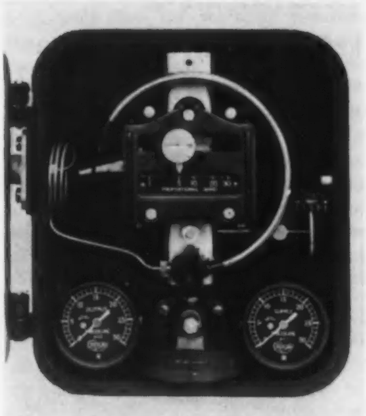
A portable, electronic, secondary-pressure standard employing direct conversion of input pressures to a digital frequency modulated signal and designed for rapid, accurate line and process-stream pressure checks offers many advantages over existing standards, according to the manufacturer, Borg-Warner International Corporation. The Vibromanometer is said to accommodate wide pressure ranges, and to provide rapid response time and accurate operation from remote points. Readout, visual or printed, is adjustable for any desired measurement unit, such as lb/in², % of full-scale, millibars, etc. The Vibromanometer incorporates a Vibrotron transducer which accepts pressure inputs ranging from zero to 10,000 lb/in² and converts these analogue pressures directly to a precise digital-frequency (electrical) output. The Vibrotron transducer operates by means of a vibrating wire which is stretched between an anchor point and a pressure-sensitive metal diaphragm. The stretched wire is set into motion in a permanent magnetic field by an alternating current through the wire, current being supplied by a special Vibrotron amplifier. Pressure changes are reflected as frequency changes in the vibrating wire and an electrical output is fed directly to a processing unit which applies scale adjustment, linearization and zero suppression, and provides a visual numerical signal which may be related to pressure as either an actual value or per cent of full scale (or any fraction thereof). The unit operates from standard power, 117 V a.c. 50–60 c/s.

Tick **No 109** on reply card

PRESSURE CONTROLLER

increased valve stroking speed

The new Mason Neilan air-operated pressure controller (model No 2807) is normally used mounted directly on the yoke of the control valve, but can also be used remotely mounted. The instrument has many features basically similar to the proved No 2707, but amongst the additional advantages which are claimed is a pilot relay of the non-bleed slack diaphragm type which has a large air capacity, and enables a much greater valve stroking speed to be achieved. This pilot valve is interchangeable with that of the 12,800 series Mason Neilan level controller. The proportional mechanism incorporates a bellows-operated negative-feedback system giving maximum sensitivity and reproducibility. With this proportional mechanism the proportional band can be adjusted to 1% of the instrument range, thus enabling the controlled pressure to be kept within close limits even when wide load changes are experienced. The pressure element which is available in



The proportional band can be adjusted to 1% of the instrument range

bronze or stainless steel can be either of the bourdon tube or bellows type, covering all ranges from full vacuum up to 10,000 lb/in². The whole instrument is sturdy and simple to operate and maintain; it is suitable for outdoor use and will withstand up to 50% over-loading of the pressure. The normal supply pressure is 20 lb/in² with the international standard output signal of 3–15 lb/in². The valve is manufactured in this country by the Crosby Valve and Engineering Co Ltd.

Tick **No 110** on reply card

VOLTMETER

for very low frequencies

Just developed, and now available from Crompton Parkinson is a special type of voltmeter which will be of particular interest to engineers who are faced with the problem of reading steady r.m.s. voltage values on very low frequency, 3-phase a.c. supplies. Such a problem arises, for example, when, for the operation of nuclear reactor control rods, use is made of very low-speed motors on a 3-phase a.c. supply, the frequency of which varies from zero to 2 c/s. When taking voltage measurements at these low frequencies, the instantaneous value of voltage varies so slowly that the pointer of an ordinary instrument has time to follow it, instead of indicating a steady r.m.s. value.

The new instrument is basically a d.c. moving-coil voltmeter operated from a phase-splitting network with full-wave rectification. This network produces twelve impulses per cycle across the instrument movement, thus reducing the magnitude of the applied ripple voltage and simultaneously increasing its frequency. As a result, the instrument may be used to indicate the r.m.s. value of an applied 3-phase voltage at any frequency from 0 to 2500 c/s.

Tests have shown that the pointer deviation either side of the mean indication amounts to no more than 0·3% at 2 c/s, 0·7% at 1 c/s and 5% at 0·04 c/s. Both switchboard and portable forms of the instrument are available.

Tick **No 111** on reply card

TEMPERATURE CONTROLLER

possesses novel mercury switch

A new temperature controller has a novel positive-action mercury relay switch. The mercury-in-steel actuated 4 in. dial thermometer is connected to a control unit having one temperature-operated pointer, and one or two adjustable pointers which can be set to make or break. The standard energizing coils operate on 100 to 440 V a.c. 50 c/s. The relay switch has a

The dial on the temperature control unit has one temperature-operated and two adjustable pointers

contact loading of 30 A 240 V a.c. for a single pole and 5 or 15 A up to 440 V a.c. for up to 3 poles. The minimum differential is ± 0·5% of scale range. Any temperature range from −20 deg F to +1000 deg F or

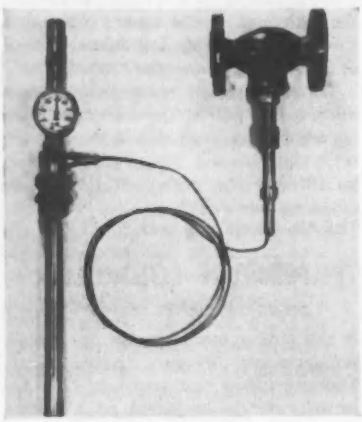
equivalent degrees centigrade with a minimum coverage of 30 deg C can be provided. The controller is made by the British Rototherm Co Ltd.

Tick **No 112** on reply card

TEMPERATURE CONTROLLER

self contained

The Kosmos temperature regulator incorporates a labyrinth thermostat, permitting sensitive and accurate adjustment, is fully self contained and requires no electricity, compressed air or other outside source of motive power. The regulator is supplied in sizes up to 6 in. with balanced double-seated valves or with balanced or unbalanced



Temperatures can be kept to fine limits without an outside source of power

single-seated valves to suit individual requirements. Every unit is complete with steam valve, thermostat, up to 100 ft of capillary tubing and a screwed or flanged pocket for installation. It can control temperatures between − 4 and + 572 deg F. The temperature range is adjustable over 176 deg F and may be altered in stages of up to 68 deg F during operation. A dial indicator is fitted but a vertical indicator is available. KDG Instruments Ltd are aided in the UK distribution by M. B. Robson & Co.

Tick **No 113** on reply card

GALVANOMETER AMPLIFIER

high gain, low noise level

A transistor galvanometer amplifier has been designed by Sir W. G. Armstrong Whitworth Aircraft Ltd to drive viscous damped recording galvanometers, which normally have a resistance of 50 ohms and a working range of d.c. to 3000 c/s. The amplifier has a switched attenuator at its input, and will accept single ended or push-pull signals from ± 1 mV to ± 500 V, and will feed a minimum of ±50 mA to the galvanometer. The main features of this amplifier are high gain with extremely low noise level, and low order of drift. There are 5 ranges of input attenuator plus a gain control, and it is portable. The gain of this unit is a maximum of 7·5 mA/mV, and the minimum of 0·05 mA/V for single ended input. The noise level of the amplifier is less than 10 μV at the input. Its input impedance is 40,000 ohms at minimum attenuator setting, and 110,000 ohms on all other ranges. There is a wide range of ancillary units available for use with the amplifier as part of an instrumentation system. The physical dimensions of this unit are 4¼ × 2¾ × 10 in. The power supply requirements are ± 6 volts d.c., 220 mA on each line.

Tick **No 114** on reply card

RECORDING HYGROMETER

claimed to be world's finest

A simple instrument announced by Shaw Moisture Meters gives immediate and continuous recording of the humidity of the most 'dry' gases. The recording hygrometer gives full scale deflexion for readings of 5% relative humidity or less and also gives warning of any increase in humidity in less than one second. Owing

Useful for checking the humidity of the dry gases found in many industries

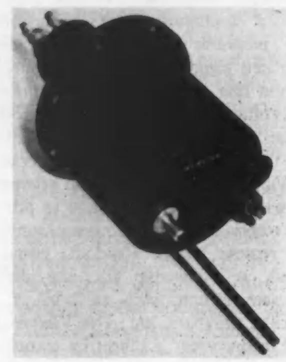
to the long term stability no knobs or controls are fitted. The sensing of moisture is done by a new type of small element in the form of a variable capacitance, and because of this contamination does not present the difficulties experienced with hygrometers which use conductive type elements. The detecting element consists of a capacitor with a hygroscopic dielectric only a few microns thick, covered with 24 carat gold. The hygrometer has an immediate response, stable characteristics and provision for checking and standardizing.

Tick **No 115** on reply card

GAS PRESSURE TRANSMITTER

with low hysteresis

A new electrical gas pressure transmitter has been designed to operate on the force balance principle. The gas pressure to be measured is fed into the main sensing element and if the requirement is for the measurement of absolute pressures, an aneroid compensating assembly is incorporated to compensate for a change in ambient conditions. The force developed in the main sensing element is communicated to the armature of a linear type inductive pick-off. The electrical output from the



The transmitter can be used for feeding absolute pressure signals to a controller or data logger

pick-off is fed to an amplifier which in turn feeds a signal to a servomotor generator. The servo which has a high starting torque drives through a number of gears to a mechanical arrangement which varies the rating in a spring to produce a balance in the assembly. The movement of the spring unit is fed to a pick-off providing an electrical signal proportional to the prime pressure signal. There are four ranges from 0 to 6000 mm Hg up to 0 to 150 mm Hg. The accuracy is ±0·25% of range and the response is 10 msec. The operating temperature range is 0 to ±90 deg C. The electrical input is 115 V a.c. at 400 c/s and the electrical output is 0–20 V. The manufacturers are Appleby and Ireland Ltd.

Tick **No 116** on reply card

SYNCHRONOUS TIMER

another record?

This month's new product from the Electrical Remote Control Co Ltd has the lengthy title of a miniature automatic multiple circuit multiple interval synchronous timer, type AMS. The makers claim that it is the smallest fast resetting multiple circuit multiple interval timer manufactured in the UK. The switching capacity is 10 A 250 a.c. non-inductive and 6 A 250 a.c. inductive. The dimensions are 2¾ × 3½ × 6½ in. There are ten standard ranges from zero to 30 sec up to zero to 48 h. The timer can be reset within ⅛ sec.

Tick **No 117** on reply card

MERCURYLESS INSTRUMENTS

one more for the Commander

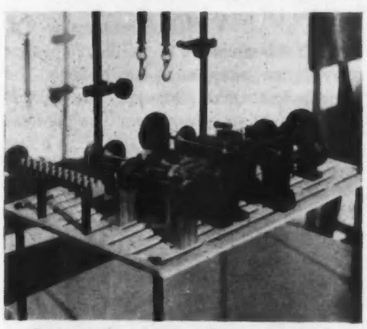
It has just been pointed out by George Kent Ltd that they have added the Kent-Barton mercuryless diaphragm instrument to their Commander range. The instrument can measure differential pressures in six maximum ranges and up to 250 lb/in² working pressure. It is available as a circular chart recorder, sector-scale indicator or as a circular-scale indicator and incorporates the Barton patented rupture-proof differential unit, which employs a sensitive bellows for its actuating element. Full line pressure can be applied across the bellows unit in either direction without damage, irrespective of the differential-pressure range of the instrument. The torque-tube drive for conveying bellows movement to the instrument-index mechanism is leakage-free and requires no periodic lubrication, being almost frictionless for the life of the instrument. Only the bellows exteriors are exposed to the metered fluid, and the unit is completely self-draining or venting.

Tick No 118 on reply card

SERVOKITS

aid training, development

A useful range of kits for constructing servomechanisms has been produced by Pioneer Designs Ltd. Angle brackets can be fitted to a slotted baseboard and from them can be supported shafts carrying gears, synchros, servomotors, differentials, potentiometers, terminal plates and similar items. The split-hub gears are a push fit on the shafts and are secured in place by a dynamically-balanced hub clamp. The shaft hangers have needle roller bearings and the shafts themselves are of hardened stainless steel. The level gear differentials are available with interchangeable end gears which are held in position on the machined hubs of the level gears by removable clamp plates. The kits are comprehensive and seem to be reasonably priced.



A typical set-up of some servo components on a baseboard

Tick No 119 on reply card

NYQUIST DIAGRAM PLOTTER

automatic, versatile

An automatic Nyquist diagram plotter is to be manufactured by Servo Consultants Ltd. The plotter is in a cabinet 27 × 25 × 20 in. and has a frequency range of 0·25 to 100 c/s. The amplitude and phase angle accuracies are 1% and 1° respectively. The instrument consists of an electromechanical frequency generator producing a signal which is applied to the system under test. This signal can be either a sinusoidal waveform at the test frequency or a modulated carrier signal. The frequency of the generator is controlled by an automatic programming switch to a high degree of accuracy. The signal from the system under test is received by the Nyquist diagram plotter, and after suitable amplification applied to two servomechanisms operating a printing head. One of them is an accurate phase detector which measures the phase angle between the outgoing and the incoming test signals. The other servomechanism indicates the amplitude of the incoming signal. The plot is obtained in the form of a number of definite frequency markers which can be easily identified.

Tick No 120 on reply card

COMB RELAY

longer life, less adjustment

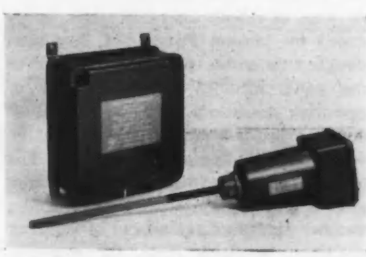
A greater number of contact units than has been accommodated before on a standard 3000-type relay is claimed to be provided on the comb relay recently brought forward by Siemens Edison Swan Ltd. Up to ten contact actions may be fitted. The new relay is a development of the standard 3000-type relay, and has been designed to give a mechanical life of 100 million operations without need for readjustment, whilst retaining the characteristics of the older relay. The spring set lifting pins have been replaced by a lifting comb of synthetic resin-bonded paper which bears directly on the metal of the armature. Siemens report that exhaustive life tests have shown that this arrangement gives less mechanical wear and reduces the frequency of readjustment and replacement.

Tick No 121 on reply card

LEVEL CONTROL

a robust, transistorized unit

A capacitance-operated level control and indication equipment by the Lancashire Dynamo Electronic Products Ltd has two versions. The single-level control will be known as the TLC 1 and multi-level as the TLC 2. With the high level probe unit, oscillation occurs in a transistor circuit when the probe is clear of the material and under these conditions the relay in the control unit is energized. When the material reaches the level of the probe, the change in capacitance causes the oscillation to be reduced and finally cease. The reduced amplitude of oscillation is detected by a further transistor circuit which in turn releases the control relay. In the low level probe head unit, the system operates in reverse, the relay in the control unit being energized when the probe is completely immersed. In both high and low level control, the circuit is so arranged that failure of equipment or supply will cause the installation to fail safe. Four types of probe are available for different materials. The unit in sensitive form is capable of operating for changes of capacitance of $\pm 2\mu\mu$ F. Excellent long term stability, and stability against supply voltage changes is claimed. Operation is possible at ambient temperatures up to 50 deg C. Feed or alarm circuits include one pair of normally open and one pair of normally closed contacts, isolated from each other and from internal power supplies, and rated for non-inductive watts at 5 A 230 V or 1 A 440 V 50 c/s a.c.



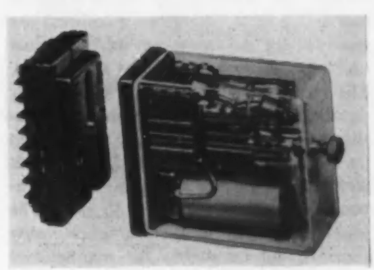
One of the level probes and its control box

Tick No 122 on reply card

PLUG-IN RELAYS

two firsts claimed

The Clifford & Snell plug-in relay system has been extended by two new products. The first, the plug-in d.c. mains relay (type 2600B) is for use where the supply is from about 110 to 240 volts d.c. The contacts are of arc suppressing material and two of them have permanent magnet arc blow-outs. These latter contacts can be used to switch small motors, klaxons and similar inductive loads taking up to about 5 A at 240 V d.c. without any risk of an arc being maintained between the contacts. The other contacts can be used on 240 V d.c. to switch such loads as 1 A and relay coils. A total of six pairs of contacts can be fitted and the coil can be for a.c. or d.c. This is claimed to be the first plug-in relay made for this duty.



The mercury switch plugs easily and neatly into the socket

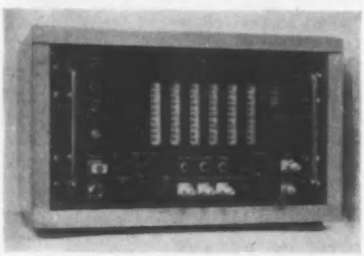
The second product, the plug-in mercury

switch relay (type 2600H) is also claimed to be the first of its kind. It can have one or two mercury switches with n/o or n/c action rated at 6 A at 500 or 240 V d.c.: or a fleeting contact or quick-strike mercury switch which gives a brief make when the relay is energized, but not when it is released, or the reverse. When only one mercury switch is fitted the relay can also have up to three pairs of dry contacts. The mercury switches move through a much greater angle than the armature, and this gives a safety margin. The sole distributors for both relays are D. Robinson & Co.
Tick **No 123** on reply card

FREQUENCY, TIME COUNTERS

competitive prices

The complete range of Rochar frequency and time counters are now marketed by Metrix Instruments Ltd. The model A478 covers the frequency range 10 c/s to



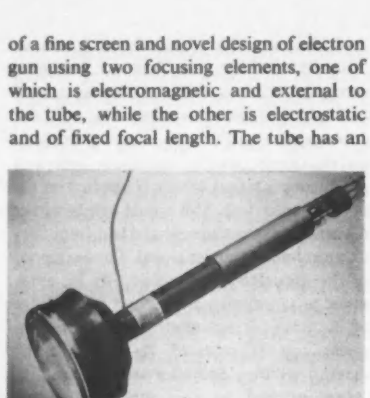
Measures all time intervals from 1 μsec upwards

1·2 Mc/s with an accuracy of 1 in 105. All time interval measurements from 1 μsec upwards can also be made. A thermostatically controlled 100 kc/s crystal oscillator is employed as the basic time-base circuit in conjunction with decade multipliers and dividers. Facilities are provided for the connexion to an external oscillator of higher stability if required. The count capacity is 999,999 (a further significant figure is available on an alternative model), and the digits are recorded on an illuminated display. The input range is 20 mV – 50 V r.m.s. and the input impedance is 1 megohm at 40 $\mu\mu$F. The instrument is of unit construction using standard sub-assemblies for maintenance or replacement. Other models in the range cover frequencies from 2 c/s to 220 Mc/s.
Tick **No 124** on reply card

CATHODE-RAY TUBE

the only one of its kind

A new micro-spot cathode-ray tube capable of resolving 5000 lines is now available from the Electronics Department of Ferranti Ltd. Measuring 5 in. across the 7/71 CM tube has been developed for airborne applications such as aerial mapping. The spot size is considerably less than 0.001 in. in diameter. The high resolution of the tube has been made possible by the use of a fine screen and novel design of electron gun using two focusing elements, one of which is electromagnetic and external to the tube, while the other is electrostatic and of fixed focal length. The tube has an



A fine screen and novel electron gun account for the high resolution of this tube

optical flat face with a non-darkening glass and a short cylindrical bulb, coated—except over the screen surface—with a thick layer of plastic resin, enabling it to be operated under adverse atmospheric conditions, viz. 30 kV at 75,000 feet without danger of e.h.t. breakdown. Whilst the new tube is primarily intended for the display or photography of repetitive information, single transients may be photographed at writing speeds which are limited by the scan coil requirements. The standard phosphor used in the tube has green fluorescence, decaying to 1/e level within ten microseconds after removal of excitation. It is also suitable for use with many types of photographic material.
Tick **No 125** on reply card

SMOKE CONTROL

safeguards boiler users

Two new items for smoke control have been produced by Londex Ltd. The first, a smoke alarm unit, provides warning by indicator lamps and single-pole changeover output contacts. It has been built to comply with BS 2740, and is suitable where the light beam through the smoke does not exceed 10 ft. The second, a smoke density unit, provides continuous monitoring of the smoke by a meter, with a printed record if required by the addition of a recorder. The power consumption is about 150 W.
Tick **No 126** on reply card

QUICK LOOKS

A range of **cylinder-operated valves**, introduced by Maxam Power Ltd, has been designed to ensure positive movement of the valve member under extremes of operating conditions. They are single or double cylinder-operated, 2-way, 3-way or 4-way valves of $\frac{3}{16}$ and $\frac{1}{2}$ in. sizes. The large piston area provided by the cylinder gives a greater thrust to the valve sliding member, safeguard against out-of-sequence operation, resulting from, for example, adverse weather conditions.
Tick **No 127** on reply card

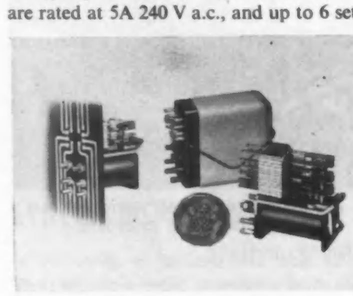
A new high-brightness, high-sensitivity instrument **cathode-ray** tube employing helical post-deflexion acceleration has been announced by Mullard Limited. The tube has a 4 in. diameter flat screen and an overall length of only 12 in. It uses electrostatic focusing and deflexion, and is suitable for double symmetrical operation.
Tick **No 128** on reply card

A new plastic cased **electrolytic** claimed to have greatly improved operating characteristics has been produced by The Plessey Company Ltd. Developed from an original model designed and patented by Plessey some years ago, the new electrolytic has been subjected to exhaustive life testing in order to obtain a higher maximum upper temperature limit ($\pm$70 deg C).
Tick **No 129** on reply card

A **process timer** by Engel and Gibbs Ltd embodies a synchronous motor and clutch mechanism, and is provided with 4 change-over contacts rated at 6A 230V a.c. The timer is adjustable in five ranges from 0·3 sec to 6 h. The unit is robust and overall size is 6×6×3 in. The timing is accurate to $\frac{1}{2}$% of any set time.
Tick **No 130** on reply card

Two advanced ranges of high temperature **plugs and sockets**, capable of operating in conditions of supersonic flight have been produced by The Plessey Company Ltd. These connectors, which are improved designs of the aluminium Mark 4 and Standard ranges of plugs and sockets, have been proved to be efficient at temperatures of up to +130 and +150 deg C.
Tick **No 131** on reply card

The P.3 **sub-miniature** Post Office 3000-type relay is an attempt to scale down the versatile Post Office 3000-type, but without losing any of its advantages. The contacts are rated at 5A 240 V a.c., and up to 6 sets



The small P.3 relay can be mounted directly to a printed circuit

of mixed contacts can be fitted. The maximum dimensions are 1·7 × 1·5 × 0·8 in. The P.3 is made by PAR Ltd and the sole distributors are D. Robinson & Co.
Tick **No 132** on reply card

An instrument developed by Blick Time Recorders Ltd records the **day**, the **time** and **serial number** of components passing along a production line. The record is printed on a continuous paper roll.
Tick **No 133** on reply card

INDUSTRIAL PUBLICATIONS

A classified and comprehensive **bibliography** (2500 English and foreign references) on semiconducting materials and transistors, compiled by the Newmarket Transistor Co. **131**

An **interchange scheme** for programmes for the Mercury computer is detailed in a stencilled Ferranti booklet: also lists available programmes. **132**

Aveley Electric, British agents for a number of foreign firms (including Rhode Schwarz, Telefunken, Cascade Research, Narda, Bang & Olufsen) have issued the first of a regular **series of bulletins** on the products they handle. **133**

Miniature relays, smoke alarm equipment and a photoelectric transistor unit are among **equipment listed** in the Londex Data Book on their relays and electrical automatic control apparatus. **134**

A four-page brochure, with diagrams, on subminiature **coaxial connectors** made by Plessey. **135**

A new edition of 'Electrical Insulation' from Langley London Ltd covers their **range of insulation materials** and services: informative, well produced, with colour illustrations. **136**

An EMI folder outlines **closed-circuit television** equipment: emphasis on applications and executive appeal. **137**

'Molybdenized Lubricants' describes Rocol's range of these products: includes general and industrial uses, and user comments on specific applications. **138**

A brief Classified Index of **Computer Literature,** with particular reference to their own equipment, issued by the Ferranti Computer Department. **139**

A Muirhead bulletin gives description and specification of a two-phase low frequency **decade oscillator,** which also forms part of their transfer function analyser. **140**

The extensive range of **'Sonocolor'** magnetic recording tape, described by UK distributors Tape Recorders (Electronics) Ltd. **141**

Perkin-Elmer 'Instrument News' is a round-up of their activities in the US and Europe: information on products and personalities. **142**

Diagrams and performance data of **propeller fans** for ring and diaphragm mounting are given in a Fenton Bryn booklet. **143**

Flame-failure safeguard for automatic burners is introduced in a detailed catalogue from Fireye Controls Co. **144**

A specification on a series of low-cost diffused **silicon rectifiers,** from Texas Inc. **145**

Johnson, Matthey & Co's **'Platinum Laboratory Apparatus'** gives advice on the care and maintenance of their equipment, as well as technical details. **146**

For further information on any industrial publication tick the corresponding number on the prepaid reply card opposite.

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CONTROL BUYERS' GUIDE 1958

ADDITIONS AND CORRECTIONS—2

DECEMBER 1958

Lists of additions and corrections will be published from time to time in CONTROL. *Additional copies of Buyers' Guide, separately bound, can be purchased from* CONTROL *3 Percy St, London, W1, price 3/6 post free.*

ADDRESS SECTION

Add the following

ENGINEERING APPLIANCES LTD
106 Victoria Street, Westminster, London, SW1
tel: Victoria 4043

HARTONS INSTALLATIONS LTD
Maxim Road, Crayford, Kent
tel: Bexleyheath 6246

HAWNT & CO LTD
59 Moor Street, Birmingham 4 tel: Central 6871

MAXAM POWER LTD
Redruth, Cornwall tel: Camborne 2261

MIMIC DIAGRAMS LTD
Maxim Road, Crayford, Kent
tel: Bexleyheath 6246

NEWMARK LTD, LOUIS (Instrument Division)
Purley Way, Croydon tel: Croydon 5571

S. E. LABORATORIES LTD
606 North Feltham Trading Estate, Feltham, Middx
tel: Feltham 5876

TELEMETERS LTD
119 Victoria St, SW1 tel: Victoria 2670

The telephone number of
BROWN LTD, S. G
should read tel: Watford 27241

The address of
DICTOGRAPH TELEPHONES LTD
should read
Abbey House, Westminster, London, SW1
tel: Abbey 5572

The telephone number of
ELECTRONIC SWITCHGEAR (LONDON) LTD
should read
tel: Letchworth 1853

The address of
HOLIDAY & HEMMERDINGER LTD
should read
71 Ardwick Green North, Manchester 12
tel: Ardwick 6366

The telephone number of
HYMATIC ENGINEERING CO LTD, THE
should read
tel. Redditch 3621

The address of
INSTRUMENT INSTALLATION LTD
should read
High Street, Cookham-on-Thames, Berks
tel: Bourne End 1414

The telephone number of
MEASUREMENT LTD
should read tel: Delph 424

The address of
PARKINSON & COWAN INSTRUMENTS
should read
PARKINSON COWAN INSTRUMENTS
7/17 Fitzalan Street, SE11 tel: Reliance 2406

Due to closing down of production the following firm should be deleted from the Buyers' Guide:
PRINTED CIRCUIT DEVELOPMENTS LTD
Guildford Road, Bisley, Surrey

The telephone number of
THE SKEFKO BALL BEARING CO LTD
should read
tel: Luton 5700

The address of
STEIN ATKINSON VICKERS HYDRAULICS LTD
should read
197 Knightsbridge, London, SW7
tel: Knightsbridge 9641

The telephone number of
TYLORS OF LONDON LTD
should read
tel: Burgess 2631

BUYERS' GUIDE

Accelerometers
add
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division

Actuators—electric
add
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division

Actuators—hydraulic (cylinders)
add
Jones Tate & Co Ltd

Actuators—pneumatic (cylinders)
add
Jones Tate & Co Ltd

Air Compressors
add
Arnold Goodwin Ltd
delete
British Thomson-Houston Co Ltd, The
Farrow & Sons Ltd
Foxboro-Yoxall Ltd

Aircraft Instruments
add
Newmark Ltd, Louis. Instrument Division
delete
Parkinson Cowan Instruments
Pye & Co Ltd, W. G
Cambridge Instrument Co Ltd

Alarms—liquid level
add
Electronic Switchgear (London) Ltd
Hawnt & Co Ltd
Parkinson Cowan Instruments
delete
Watford Electric & Manufacturing Co Ltd

Alarms—miscellaneous
add
Foxboro-Yoxall Ltd
Jones Tate & Co Ltd
delete
WS Electronics (Production) Ltd

Alarms—radiation
add
Hawnt & Co Ltd

Alarms—temperature
add
Foxboro-Yoxall Ltd
delete
Watford Electric & Manufacturing Co Ltd

Amplifiers—a.f.
add
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division

Amplifiers—d.c.
add
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division
Nuclear Research Applications Ltd

Amplifiers—magnetic
add
Newmark Ltd, Louis. Instrument Division
delete
Addison Electric Co Ltd
Foster Transformers Ltd
Hymatic Engineering Co Ltd, The
Lee Products (Great Britain) Ltd
Morris Ltd, John
Pye & Co Ltd, W. G
Servomex Controls Ltd

Amplifiers—pneumatic
add
Foxboro-Yoxall Ltd

Amplifiers—r.f.
add
Hawnt & Co Ltd

Annunciators
add
Mimic Diagrams Ltd
delete
WS Electronics (Production) Ltd

Balancing machines—dynamic
add
Hawnt & Co Ltd

Ball bearings—miniature
delete
Dick Ltd, R. & J
Ransome & Marles Bearing Co Ltd
Tormo Ltd
Townson & Mercer Ltd

Batteries—dry
add
Hawnt & Co Ltd

Batteries—storage
add
Hawnt & Co Ltd
delete
Dunlop Rubber Co Ltd

Bellows—metallic
add
Engineering Appliances Ltd

Boiler controls and instrumentation
add
Hartons Installations Ltd

Bridges—a.c.
add
Hawnt & Co Ltd

Bridges—capacitance
add
Hawnt & Co Ltd

Bridges—conductivity
add
Electronic Switchgear (London) Ltd
Hawnt & Co Ltd

Bridges—d.c.
add
Hawnt & Co Ltd
delete
Mullard Ltd

Bridges—impedance
add
Hawnt & Co Ltd
delete
Pye & Co Ltd, W. G

Bridges—inductance
add
Hawnt & Co Ltd

Bridges—resistance
add
Hawnt & Co Ltd
delete
Measuring Instruments (Pullin) Ltd
Mullard Ltd

Bridges—schering
add
Hawnt & Co Ltd

Bridges—strain gauge
add
Hawnt & Co Ltd

Bridges—wattmeter
delete
Measuring Instruments (Pullin) Ltd

Bridges—universal
add
Hawnt & Co Ltd

Calling systems
add
Dictograph Telephones Ltd

Cameras—high speed
delete
Airtech Ltd

Cameras—oscilloscope recording
add
Hawnt & Co Ltd

Choppers
delete
Parkinson Cowan Instruments
Wright & Wealre Ltd

Clutches—magnetic particle
add
Newmark Ltd, Louis. Instrument Division
delete
Burnand & Son Ltd, W. E
Comucate Ltd
Peebles & Co Ltd, Bruce

Combustion controls—automatic
add
Foxboro-Yoxall Ltd
Hartons Installations Ltd

Comparators—electronic
add
Hawnt & Co Ltd

Comparators—impedance
add
Hawnt & Co Ltd

Computers—analogue
add
Newmark Ltd, Louis. Instrument Division

Conductivity—controllers, indicators and recorders
delete
Measuring Instruments (Pullin) Ltd

Contactors
add
Hawnt & Co Ltd

Control Installation Engineers
add
Hartons Installations Ltd
Hawnt & Co Ltd
Jones Tate & Co Ltd
Newmark Ltd, Louis. Instrument Division
Parkinson Cowan Instruments
Thompson Instrument Co Ltd, John
delete
English Electric Co Ltd, The
Fisher Governor Co Ltd
Nuclear Research Applications Ltd

Counters—batch
add
Electronic Switchgear (London) Ltd
Hawnt & Co Ltd

Counters—binary
delete
Evershed & Vignoles Ltd
Measuring Instruments (Pullin) Ltd

Counters—decade
add
Electronic Switchgear (London) Ltd
Hawnt & Co Ltd
Nuclear Research Applications Ltd
delete
Measuring Instruments (Pullin) Ltd

Counters—electrical impulse
add
Hawnt & Co Ltd
delete
Evershed & Vignoles Ltd
Measuring Instruments (Pullin) Ltd

Counters—electronic
add
Hawnt & Co Ltd
Mullard Ltd (Tubes)
Nuclear Research Applications Ltd
delete
Mullard Ltd

Counters—photocell
add
Hawnt & Co Ltd

Counters—radiation
add
Hawnt & Co Ltd
Nuclear Research Applications Ltd

Counters—revolution
add
Falk & Co Ltd, M
Hawnt & Co Ltd
delete
Evershed & Vignoles Ltd
Mullard Ltd
Pye & Co Ltd, W. G

Counters—scintillation
add
Hawnt & Co Ltd
Nuclear Research Applications Ltd

Data processing systems
delete
Mason & Sons Ltd, E. N
WS Electronics (Production) Ltd

Data transmission elements
delete
British Tabulating Machine Co Ltd, The
Ferranti Ltd
Plessey Co Ltd, The
WS Electronics (Production) Ltd

Densitometers
add
Falk & Co Ltd, M

Density Controllers
add
Hawnt & Co Ltd

Differential pressure-controllers, indicators and recorders
add
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
Thompson Instrument Co Ltd, John

Differential transformers
add
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division

Diodes—crystal—germanium—etc.
add
Hawnt & Co Ltd

Draught indicators
add
Thompson Instrument Co Ltd, John

Filters—electrical wave and frequency
delete
Turner Electrical Instruments Ltd, Ernest

Filters—interference
delete
Mullard Ltd

Filters—liquid
delete
Nuclear Engineering Ltd
Simmonds Aerocessories Ltd

Flame failure equipment
add
Parkinson Cowan Instruments
delete
Electronic Switchgear (London) Ltd

Flow controllers, indicators and recorders
add
Foxboro-Yoxall Ltd
Parkinson Cowan Instruments
delete
Mechanical & Electronic Products (London) Ltd
Watford Electric & Manufacturing Co Ltd

Frequency controllers
delete
Parkinson Cowan Instruments

Frequency response meters
add
Hawnt & Co Ltd

Galvanometers
add
Hawnt & Co Ltd

Gas Analysers
delete
Measurement Ltd
Watford Electric & Manufacturing Co Ltd

Gearing—precision
add
Gear Grinding Co Ltd, The
Newmark Ltd, Louis. Instrument Division
Stuart Davis Ltd

Generators—a.c.
add
Hawnt & Co Ltd

Generators—d.c.
add
Hawnt & Co Ltd

Generators—noise
add
Hawnt & Co Ltd

Generators—pulse
add
Hawnt & Co Ltd
Nuclear Research Applications Ltd

Generators—sweep
add
Hawnt & Co Ltd

Generators—ultrasonic
add
Hawnt & Co Ltd

Gyros—directional
add
Newmark Ltd, Louis. Instrument Division

Gyro—stabilizers
add
Newmark Ltd, Louis. Instrument Division

Gyros—vertical and rate
add
Newmark Ltd, Louis. Instrument Division

Harmonic Analysers
add
Hawnt & Co Ltd

Heat flow indicators and recorders
add
Foxboro-Yoxall Ltd

Industrial and process control systems
Falk & Co Ltd, M
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division
delete
Fisher Governor Co Ltd

Inductance measuring equipment
delete
Measuring Instruments (Pullin) Ltd

Inductors
delete
Measuring Instruments (Pullin) Ltd

Isotopes
add
Hawnt & Co Ltd
Nuclear Research Applications Ltd

Level controllers, indicators and recorders
add
Electronic Switchgear (London) Ltd
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
Jones Tate & Co Ltd
delete
Evershed & Vignoles Ltd

Magn
add
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add
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add
Haw
delet
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Mari
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Park

Minia
add
Foxb
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Pye

Modu
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Mea

Moto
add
New
delet
Briti
Cron
Elec
Engl
Frac
Higg
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McK
Sang
Tow

Moto
add
New

Non-
add
Falk
New

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Foxb
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Pye

Nucle
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Haw
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Orific
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Tylo

Oscill
add
Haw
New
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WS

Oscill
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Pye
WS

Oscill
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Haw
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Mull

Oscill
add
Haw
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Pye

Oscill
add
Haw
Nucl
delet
Pye

Oscill
add
Haw
delet
Hatf
Park
Pless

Magnetic brakes
add
Normand Electrical Co Ltd

Magnetic recording tape
add
Hawnt & Co Ltd

Magnetic tape recorders
add
Hawnt & Co Ltd
delete
Electrical & Electronic Development Ltd

Marine instruments
delete
Parkinson Cowan Instruments

Miniature instrumentation
add
Foxboro-Yoxall Ltd
delete
Pye & Co Ltd, W. G

Modulation indicators
delete
Measuring Instruments (Pullin) Ltd

Motors—servo
add
Newmark Ltd, Louis. Instrument Division
delete
British Thomson-Houston Co Ltd, The
Crompton Parkinson Ltd
Electro Dynamic Construction Co Ltd
English Electric Co Ltd, The
Fractional HP Motors Ltd
Higgs Motors Ltd
Hoover Ltd
McKellard Automation Ltd
Sangamo Weston Ltd
Townson & Mercer Ltd

Motors (torque)—electric
add
Newmark Ltd, Louis. Instrument Division

Non-destructive testing equipment
add
Falk & Co Ltd, M
Newmark Ltd, Louis. Instrument Division

Nuclear reactor control systems
add
Foxboro-Yoxall Ltd
Hartons Installations Ltd
delete
Pye & Co Ltd, W. G

Nucleonic apparatus
add
Hawnt & Co Ltd
Nuclear Research Applications Ltd

Orifice plates
delete
Tylors of London Ltd

Oscillators—a.f.
add
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division
delete
WS Electronics (Production) Ltd

Oscillators—microwave
delete
Pye & Co Ltd, W. G
WS Electronics (Production) Ltd

Oscillators—r.f.
add
Hawnt & Co Ltd
delete
Mullard Ltd

Oscillators—ultrasonic
add
Hawnt & Co Ltd
delete
Pye & Co Ltd, W. G

Oscillographs
add
Hawnt & Co Ltd
Nuclear Research Applications Ltd
delete
Pye & Co Ltd, W. G

Oscilloscopes—cathode ray
add
Hawnt & Co Ltd
delete
Hatfield Instruments Ltd
Parkinson Cowan Instruments
Plessey Co Ltd, The

Phase angle indicators
add
Newmark Ltd, Louis. Instrument Division

pH controllers, indicators and recorders
add
Electronic Switchgear (London) Ltd

Position indicators
add
Foxboro-Yoxall Ltd
Telemeters Ltd
delete
Measuring Instruments (Pullin) Ltd
Watford Electric & Manufacturing Co Ltd

Potentiometers
add
Hawnt & Co Ltd

Power units (a.c. and d.c.)
add
Hawnt & Co Ltd
Mullard Equipment Ltd
Nuclear Research Applications Ltd

Pre-amplifiers
delete
WS Electronics (Production) Ltd

Pressure gauges
add
Harcourt Ltd, David
Stuart Davis Ltd

Pressure controllers, indicators and recorders
add
Harcourt Ltd, David
Newmark Ltd, Louis. Instrument Division
Stuart Davis Ltd
Thompson Instrument Co Ltd, John

Printed circuits
add
Newmark Ltd, Louis. Instrument Division

Process timing instruments
add
Electric Switchgear (London) Ltd
Falk & Co Ltd, M
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
Jones Tate & Co Ltd
delete
Tylors of London Ltd
Watford Electric & Manufacturing Co Ltd

Profile indicators
add
Newmark Ltd, Louis. Instrument Division

Programme controllers
add
Electronic Switchgear (London) Ltd
Falk & Co Ltd, M
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
Jones Tate & Co Ltd
delete
WS Electronics (Production) Ltd

Proportional controllers
add
Foxboro-Yoxall Ltd

Pulse height analysers
add
Hawnt & Co Ltd

Pyrometers
delete
Measuring Instruments (Pullin) Ltd
Zeal Ltd, G. H

Quality control equipment
add
Foxboro-Yoxall Ltd

Ratemeters
add
Hawnt & Co Ltd
Nuclear Research Applications Ltd

Recorders—miniature
add
Hawnt & Co Ltd
delete
Cambridge Instrument Co Ltd
Ether Ltd

Recorders—multipoint
add
Electronic Switchgear (London) Ltd
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
Thompson Instrument Co Ltd, John

Recorders—potentiometric
add
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
delete
Pye & Co Ltd, W. G

Refrigeration controllers
add
Foxboro-Yoxall Ltd

Relays—a.c.
add
Hawnt & Co Ltd

Relays—electronic
add
Electronic Switchgear (London) Ltd
Hawnt & Co Ltd
delete
Measuring Instruments (Pullin) Ltd

Relays—miniature
add
Newmark Ltd, Louis. Instrument Division

Relays—pneumatic
add
Foxboro-Yoxall Ltd

Relays—temperature
add
Falk & Co Ltd, M

Relays—time delay
add
Electronic Switchgear (London) Ltd
Hawnt & Co Ltd

Remote control and supervisory apparatus and systems
add
Foxboro-Yoxall Ltd
Hartons Installations Ltd
Hawnt & Co Ltd
Jones Tate & Co Ltd
Newmark Ltd, Louis. Instrument Division
delete
Measuring Instruments (Pullin) Ltd
Tylors of London Ltd

Servo system analysers
add
Newmark Ltd, Louis. Instrument Division

Signal generators
add
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division
delete
English Electric Co Ltd, The
WS Electronics (Production) Ltd

Smoke density indicators and recorders
add
Thompson Instrument Co Ltd, John
delete
Electronic Switchgear (London) Ltd

Sound level indicators
add
Hawnt & Co Ltd

Speed controllers, indicators and recorders
add
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
delete
Measuring Instruments (Pullin) Ltd

Stabilisers
add
Hawnt & Co Ltd

Stress, strain analysers
delete
Mullard Ltd

Stroboscopes
add
Hawnt & Co Ltd

Tachometers—centrifugal
delete
Parkinson Cowan Instruments

Telemetering systems
add
Telemeters Ltd
delete
Measuring Instruments (Pullin) Ltd

Telephone and telecommunications equipment
add
Dictograph Telephones Ltd

Temperature alarm systems
add
Foxboro-Yoxall Ltd

Temperature controllers, indicators and recorders
add
Falk & Co Ltd, M
Foxboro-Yoxall Ltd
Thompson Instrument Co Ltd, John
delete
Isenthal & Co Ltd
Plessey Co Ltd, The

Thermocouples—contact type
delete
Zeal Ltd, G. H

Thermometers
add
Falk & Co Ltd, M
Foxboro-Yoxall Ltd
delete
Pye & Co Ltd, W. G

Thermostats
add
Hawnt & Co Ltd

Thickness gauges—eddy current
add
Hawnt & Co Ltd

Thickness gauges—nucleonic
add
Hawnt & Co Ltd

Thickness gauges—ultrasonic
add
Hawnt & Co Ltd

Time delays
add
Unilag Ltd

Timers and time recorders
add
Dictograph Telephones Ltd
Foxboro-Yoxall Ltd
Hawnt & Co Ltd
Newmark Ltd, Louis. Instrument Division
delete
Ilford Ltd
Tylors of London Ltd

Torque—controllers and indicators
add
Newmark Ltd, Louis. Instrument Division

Transformers—constant voltage
add
Hawnt & Co Ltd
delete
Fielden Electronics Ltd
Foster Instruments Ltd
Hackbridge & Hewittic Electric Co Ltd
Honeywell Controls Ltd

Transformers—differential
add
Haddon Transformers Ltd
Newmark Ltd, Louis. Instrument Division

Transformers—instrument
delete
Mullard Ltd
Telemeters Ltd

Transformers—power
add
Haddon Transformers Ltd
Telemeters Ltd

Transformers—rotary
add
Hawnt & Co Ltd

Transient recorders
add
Newmark Ltd, Louis. Instrument Division

Transistors
add
Hawnt & Co Ltd
delete
English Electric Valve Co Ltd
Pye & Co Ltd, W. G
Walter Instruments Ltd

Transistor test sets
delete
English Electric Co Ltd, The
Semiconductors Ltd

Tubing—glass
delete
Zeal Ltd, G. H

Tubing—metallic
add
Fine Tubes Ltd

Ultrasonic industrial equipment
add
Hawnt & Co Ltd
delete
Pye & Co Ltd, W. G

Ultrasonic instruments
add
Falk & Co Ltd, M

Valves—operated by electric motor
add
Drayton Regulator & Instrument Co Ltd, The
Jones Tate & Co Ltd
Watford Electric & Manufacturing Co Ltd
NON Electrical Ltd

Valves—hydraulically operated
add
Jones Tate & Co Ltd
delete
Honeywell Controls Ltd

Valves—pneumatically operated
add
Foxboro-Yoxall Ltd
Jones Tate & Co Ltd

Valves—solenoid operated
add
Graseby Instruments Ltd
Hydraulics & Pneumatics Ltd
Jones Tate & Co Ltd
Lang Pneumatic Ltd
Martonair Ltd
Maxam Power Ltd
Schrader's Son, A
S. E. Laboratories Ltd
Smiths Jacking Systems Ltd
delete
Fawcett-Finney Ltd
New Electronic Products Ltd
Plessey Co Ltd, The

Valves—steam operated
add
Jones Tate & Co Ltd

Valves—thermostatically operated
add
Drayton Regulator & Instrument Co Ltd, The
Jones Tate & Co Ltd

Valves (air)—flow
add
Arnold Goodwin Ltd
Foxboro-Yoxall Ltd
Stuart Davis Ltd

Valves (air)—non-return
add
Arnold Goodwin Ltd
Stuart Davis Ltd

Valves (air)—pressure regulating
add
Arnold Goodwin Ltd
Foxboro-Yoxall Ltd
Stuart Davis Ltd

Valves (air)—safety and relief
add
Arnold Goodwin Ltd
Stuart Davis Ltd

Valves (liquid)—flow
add
Foxboro-Yoxall Ltd

Valves (liquid)—pressure regulating
add
Foxboro-Yoxall Ltd

Valve positioners
add
Newmark Ltd, Louis. Instrument Division

Vibration generators
delete
Lancashire Dynamo Electronic Products Ltd

Vibration pick-ups
add
Newmark Ltd, Louis. Instrument Division
delete
Measuring Instruments Ltd

Vibration testing equipment
add
Falk & Co Ltd, M
Newmark Ltd, Louis. Instrument Division

Weight controllers, indicators and recorders
delete
Cambridge Instrument Co Ltd

Wobbulators
add
Hawnt & Co Ltd

X-ray equipment
add
Falk & Co Ltd, M

X-ray tubes
delete
Ilford Ltd

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LOOKING AHEAD

A diary for the next three months

Unless otherwise indicated, all events take place in London. BritIRE British Institution of Radio Engineers. BCS British Computer Society. IEE Institution of Electrical Engineers. RAS Royal Aeronautical Society. SIT Society of Instrument Technology

TUESDAY 16 DECEMBER
Modern Control Techniques on the Railways Discussion opened by W. J. Webb and L. A. Ginger IEE 5.30 at the Institution

WEDNESDAY 17 DECEMBER
Drone Aircraft H. G. Conway RAS 6.00 at the Institution of Civil Engineers, Great George Street, SW1

THURSDAY 18 DECEMBER
Air Traffic Control over the North Atlantic E. W. Pike RAS 6.00 at the Institution of Mechanical Engineers, Birdcage Walk, SW1

Review of the Computer Exhibition and the Business Computer Symposium H. W. Gearing and D. W. Hopper BCS 6.15 at the Northampton College of Advanced Technology, EC1

MONDAY 5 JANUARY
Control Systems as Applied to Railways Signalling J. C. Kubale SIT 6.00 at Manson House, Portland Place, W1

TUESDAY 6 JANUARY
Silicone Electrical Insulation J. H. Davis IEE 5.00 at the Institution

MONDAY 12–WEDNESDAY 14 JANUARY
5th National Symposium on Reliability and Quality Control in Electronics *See Oct. p 106*

WEDNESDAY 14 JANUARY
Symposium on Storage Media SIT 6.00 at Manson House, Portland Place, W1

MONDAY 19 JANUARY
Study of the Applications of a Computer to Production Control D. C. Hemy BCS 6.15 at the Northampton College of Advanced Technology, EC1

MONDAY 19–THURSDAY 22 JANUARY
Physical Society Exhibition Royal Horticultural Society's Old and New Halls, Westminster

TUESDAY 20 JANUARY
D.C. Amplifiers Discussion Opened by K. Kandiah IEE 5.00 at the Institution

MONDAY 26 JANUARY
Automation (Faraday Lecture) H. A. Thomas IEE 6.00 at the Royal Festival Hall Admission by ticket

TUESDAY 27 JANUARY
Symposium on Flow Measurement SIT 6.00 at Manson House, Portland Place, W1

WEDNESDAY 11 FEBRUARY
Digital Instrumentation System for use in the Testing of Jet Engines L. Airey SIT 6.00 at Manson House, Portland Place, W1

MONDAY 16–TUESDAY 17 FEBRUARY
Specialist Discussion Meetings on new digital computer techniques. Committee of the Measurement and Control Section IEE At the Institution

TUESDAY 17 FEBRUARY
Simulation of Melting Shop Operations on a Computer R. Neate BCS 6.15 at the Northampton College of Advanced Technology, EC1

THURSDAY 19 FEBRUARY
Theoretical Studies of Guided Missile Control Systems E. G. C. Burt RAS 6.00 at the Institution of Civil Engineers, Great George Street, SW1

TUESDAY 24 FEBRUARY
Symposium on Automatic Weight Control in Industry SIT 6.00 at Manson House, Portland Place, W1

THURSDAY 5 MARCH
Symposium on the Use of Data Recorded on Industrial Plant SIT 6.00 at Manson House, Portland Place, W1

WEDNESDAY 18 MARCH
Approach to Learning and Teaching Machines C. E. G. Bailey BCS 6.15 at the Northampton College of Advanced Technology, EC1

For your bookshelf

Backing hunches

Investment in Innovation** by **C. F. Carter** and **B. R. Williams
Oxford University Press. 1958. 176 pp. 15s.

A Science and Industry Committee was appointed by the Royal Society of Arts, the British Association, and the Nuffield Foundation to investigate factors influencing the rate of adoption of new scientific and technical ideas by British industry. The first report on these matters has been published.* The present book is a study of the material forming the background to investment decisions.

Control engineers will be interested in the book because it gives a broad indication of some of the difficulties that are present and which have to be overcome, before industrial concerns are willing to invest in innovations such as instrumentation and control equipment. Many investment decisions in the mid-nineteen-fifties were based upon the excess demand; there was no explicit consideration of yield. The impression left is that most of the firms studied largely placed their faith on hunches and hardly attempted to reduce the uncertainty of the future by using scientific techniques. The authors stress that unless research, design and development are closely related to the activities of production, sales and finance they may be wasted.

When there is something quite new in a project which is not fully proved the decision whether to invest or not will depend upon the confidence of the firm in its technical assessment. The study showed that firms which have research and development departments are more venturesome than those firms which lack them and are also likely to have a larger flow of innovations coming forward for consideration. The authors believe that there is an unreasonably high proportion of unconsidered projects in Britain owing to poor organization of research and development—which, they consider, is insufficient in private industry.

L. LANDON GOODMAN

Tick **No 156** on reply card

All you need on data-sampling

Sampled-Data Control Systems** by **J. R. Ragazzini** and **G. F. Franklin
McGraw-Hill. 1958. 340 pp. £3 14s.

Three steps are needed at present to acquire a useful knowledge of sampled-data system theory. First one must locate the many relevant papers scattered throughout the journals of the last decade. Next some attempt must be made to pick out the significant ones and to arrange them in a logical order. The third step involves diligent reading. Now we have a book which sets out to perform the first two steps for us. Since the task has been undertaken by such competent authors the result is a pleasing book lucidly written and well illustrated. Consequently step three becomes less tiring.

The work is intended primarily for graduates and practising engineers, with a basic knowledge of control theory. Chapter 1 introduces the idea of a discrete data link, involving data sampling, possible operations on the pulse or number sequence and the reconstruction of continuous signals, in a control system. The remainder of the system consists of continuous elements.

The next two chapters represent sampling and reconstruction as operations on the complex frequency spectra of signals. In Chapter 4 the introduction of a new complex variable $z = e^{-sT}$ is seen to facilitate handling of pulse or number sequences. Operations by continuous or digital elements introduce the concept of the *pulse transfer function* $G(z)$. The parallelism with the use of Laplace transforms for

* Carter, C. F., and Williams, B. R.: 'Industry and Technical Progress' (Oxford University Press, 1957)

continuous systems is well stressed. This finds application in Chapter 5 to the well-known transfer locus, root locus, and frequency response techniques. I feel that this long-awaited book will soon become a standard work.

J. M. NIGHTINGALE

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Good, but typewritten

Notes on Analog-Digital Conversion Techniques *edited by A. K. Susskind. John Wiley. 1958. 420 pp. £4.*

This is a good book, although the chapter on voltage-analogue to digital conversion has shortcomings. The introductory chapters deal first with the mathematical aspect of sampling and quantizing, with excellent explanations, and no rigour. Codes for digitizers are reviewed adequately, but the outline of digital circuits which follows is unsatisfactory. Here, brevity has caused misplaced emphasis, the worst example being the statement 'The function of memory can be achieved by adding feedback around an OR circuit'. (The essential feature is, of course, feedback round a delay circuit.)

The next two chapters are the ones to which the book's title refers, dealing with electrical and mechanical analogue quantities respectively. The catalogue of techniques which have been used is admirably thorough, but the electrical chapter leaves the principles hidden in the details of examples, in marked contrast to the other one. The final portion of the book relates to a particular military requirement. It opens with a useful discussion of the choice of various parameters, and goes on to describe two optical digitizers. There is a surprisingly complete survey of photosensitive devices and light sources.

The text has been produced on a typewriter, so that suffixes and indices are confusingly large. There is no index, and the numerous references are all American.

G. C. TOOTILL

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Rocket assortment

Science News 48: Rocket and Satellite Research Number. *Penguin Books. 1958. 148 pp. 2s. 6d.*

Written by seven scientists and engineers, this is a simple, authoritative guide to research in the upper atmosphere and interplanetary space and the use of rockets and earth satellites for it. However, the authors also discuss guided weapons, and an appendix gives some properties of most of the American military rockets in tabular form. A chapter on 'Guidance, Control and Instrumentation' sketches the problems involved in launching rockets, putting a satellite into orbit, and controlling a rocket vehicle in flight.

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Books received

Handbook of Automation, Computation and Control, Volume I Edited by *E. M. Grabbe, S. Ramo* and *D. E. Wooldridge.* John Wiley. 1958. £6 16s. Tick **No 160** on reply card

Dynamical Analogies (2nd Edition) by *H. F. Olson.* Van Nostrand. 1958. 290 pp. £2 11s. Tick **No 161** on reply card

Transistor Technology, Volume III edited by *F. J. Biondi.* Van Nostrand. 1958. 430 pp. £4 14s. Tick **No 162** on reply card

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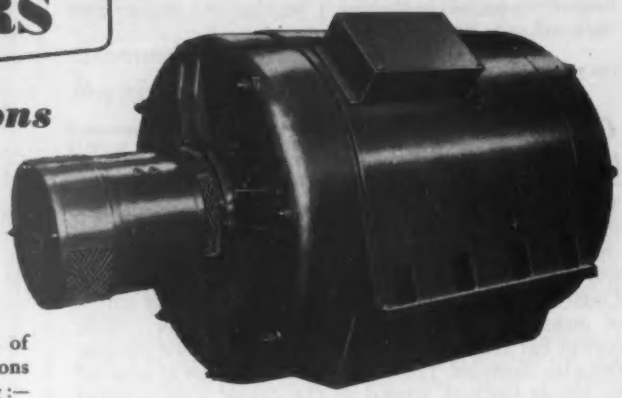

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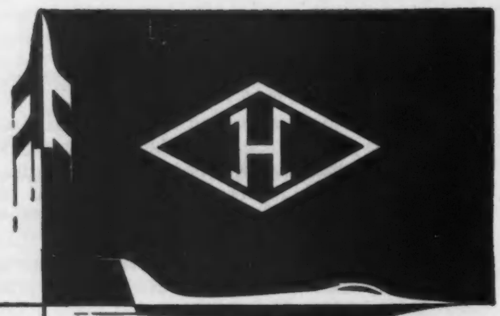

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